Lunar Gateway R2

2025

CREDIT: NASA

Report created for NSS Gerard K. O'Neill Space Settlement Contest by Devam Prajapati, Rishik Kapoor, and Seerat Kalsi

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I. CREW

Fig. 1: Source: [1]

A Vision: Our small group has three members representing Grade 10 students in Central Peel Secondary School, Brampton ON Canada. Our school is an AP school dedicated to molding the futures of many successful students heading into careers related to STEAM. As a group, we have been interested in space since childhood, and this entry reflects our knowledge and creativity compressed.

1) Devam:
Design, Formatting, Sustaining Life, Project Manager
2) Seerat:
Sustaining Life, Lunar Activities, Society
3) Rishik:
Society, Lunar Activities, Introduction, Realism

II. INTRODUCTION

Fig. 2: Source: [2]

1) Name Explanation:

The name of the settlement will be explained, along with the names of Lunar Bases. Reasons will be provided as well, with intentions.

2) General Settlement Introduction:

On this page, the settlement is introduced with all of its most significant aspects. A small insight into the rest of the report is shown in this section. Our most significant ideas are also introduced.

A. Name Explanation

Our name was chosen due to a variety of reasons. The “Gateway” part of our name comes from the Lunar Gateway. When trying to come up with ideas for our report, our minds were blank. But then we had a great idea to add on to an already great system in place. So we researched and found Lunar Gateway, we decided to use this as the base of our project. Without this incredible idea we would not have been able to find our way to the point we are at now. The name of our settlement pays homage to the Lunar Gateway for serving as a guide in navigating the difficulties and intricacies of this project.

The R2 part symbolizes us as a group. It is our second year participating in this contest. Our second revolution if you will. This serves as a reminder that even though our base is the Lunar Gateway, we have truly made it our own. This is an improvement over the Lunar Gateway. It is a truly improved and innovative take on what is known as a space settlement. This part of the name symbolizes us as a team, the hardships that we have been through, the dedication and hard work that was put into this project

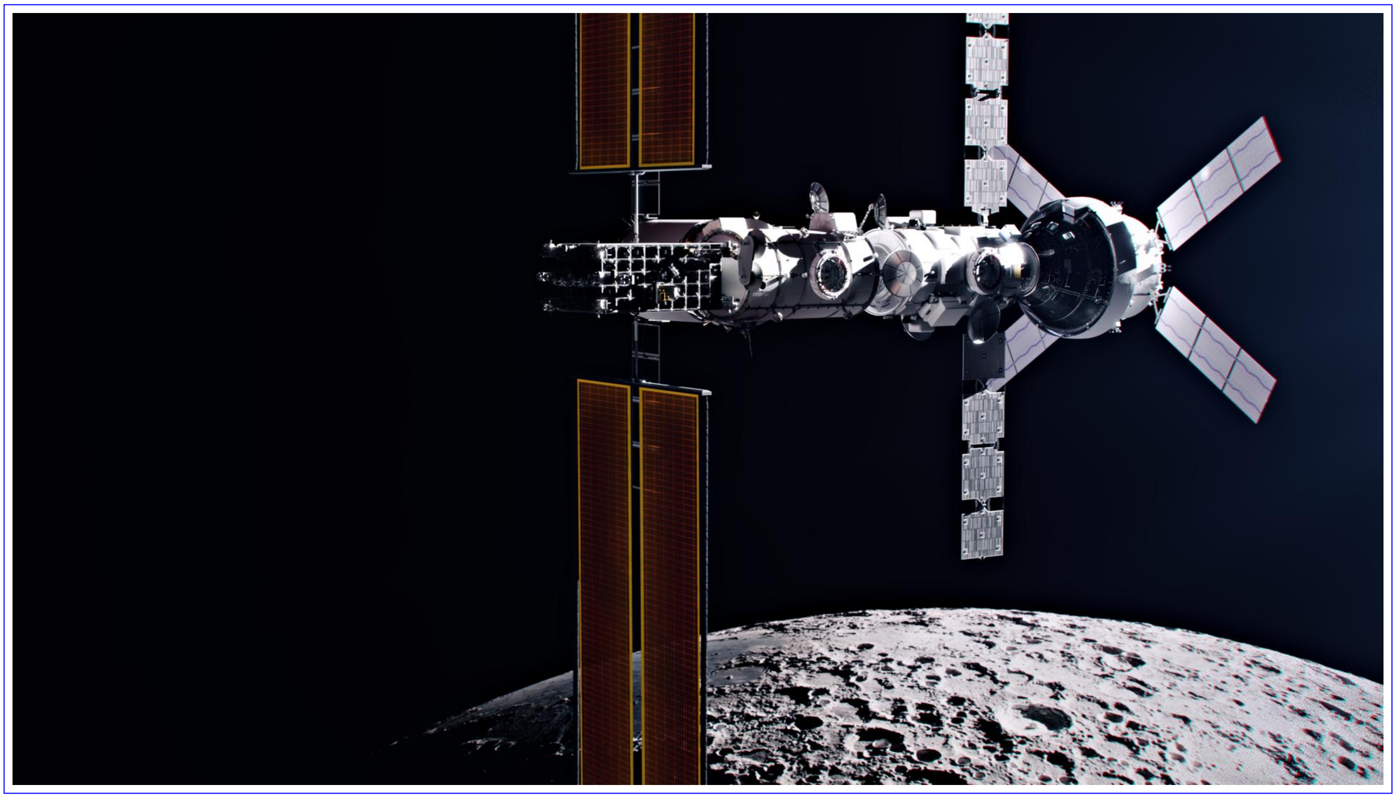


Fig. 3: Source: [3]

B. General Settlement Introduction

Our settlement is called the Lunar Gateway R2. When we started with this project, we were very confused on how to go about creating a good report. Our group had participated in this contest last year too and faced disappointment when the results came out. This was definitely discouraging, but we decided that we would not give up and go back even stronger next year, and that year is here. We wanted our project to be so unique and different that it would thoroughly impress the judges and we hope we have achieved this goal through this report. Our settlement is an extension of the already existing Lunar Gateway. It works as a foundation for us to build upon with new revolutionary ideas that create a self-sustaining settlement. The whole group is really proud of the work that has been put into our project this year, from honing it to perfecting each and every little detail.

An experiment that we did this year that we are really proud of is our Lettuce experiment. We wanted to do something innovative and different for growing methods. We have consistently seen things such as hydroponics and aeroponics seen in growing food in outer space. In fact, we used those methods as well. But we wanted to do something more, and that's when the idea of using Lunar Regolith came into our minds. This is explained more in detail later in the report, but the Lunar Regolith is basically a form of soil found on the surface of the moon. While researching this substance, we found that it has similar properties to soil but they are not all suitable for glowing plants. Lunar Regolith does not have the property to hold water as well as normal Earth soil, to combat this we use thermolysis to create biochar, a substance that gives water-holding properties to Lunar Regolith. Using this technique to grow food is extremely efficient as we have access to an abundance of Lunar Regolith on the surface of the moon. Moving forward, some species of plants can not be grown using methods such as hydroponics and aeroponics, so by using a combination of the three methods we can create a state-of-the-art farming practice in our settlement.

Another part of our settlement that I'd like to highlight are the bases that we have on the moon. Each base serves as an extension to our overall settlement. Each base is named after core values that reflect us all as a group. First we have Base Persistence. This highlights the quality in our whole group that we are persistent in trying to achieve our goals, in this case it would be winning the Grand Prize. The same type of reasons apply to each of our bases and really reflect on core values that we have developed due to this contest. Each of these bases are made for a specific purpose and task in mind. There are 2 bases located on the poles of the Moon, Base Persistence and Base Excellence. These 2 bases are specifically made to collect water. Water is an important part of our settlement, used for a variety of purposes on our settlement like hydroponics. The other bases are located on the equator of the Moon. Base Perseverance is used for collecting lunarmare, this is a substance that will be talked about later on in the report. Lastly, Base Resilience is used to collect Lunar Regolith, this substance has been talked about and will be explained further in detail as the report goes on.

The final creation that was made to impress the judges is a fully programmed website posted for the Lunar Gateway R2, introducing all of its concepts in a creative layout that informs anyone who visits the site. Please take a look if you have the chance at lunargatewayr2.my.canva.site, as it summarizes the report in a more modern way that connects to a younger audience.

These are the things that really stand out to the creators of this report. We hope that as you read along you learn something new from this report. Although the goal is to win the grand prize, this experience was very fun for the whole group and we really hope that whoever reads this will enjoy it. We wish to thank you for reading the report and hope that our report and it is a fulfilling reading experience.

III. DESIGN

Fig. 4: Source: [4]

1) Orbit:
This first section goes through the steps taken to decide the orbit, measuring pros and cons for each specific location and orbit in a reasonable range.

2) Assembly and Components:
This section is dedicated to describing each component. Every component's use is shown, as well as specific dates including manufacturing time and assembly time.

3) Materials:
The third section includes many pages about the materials used to build the settlement, dedicated to efficiency, a low mass, durability, and ability to protect the settlement from debris. Radiation protection materials are also covered.

4) Subsystems:
The final part includes the settlement's subsystems related to design. These include radiation protection, artificial gravity, propulsion, and automation.

A. *Orbit*

One of the most significant aspects of our settlement is its orbit. We decided not to choose a location past Mars due to communication issues, high costs, and difficulty in assembly. Below is a discussion of the pros and cons of each location, followed by a comparison of Lunar orbits.

1) Earth: Benefits include:

- Any orbit around Earth will allow fast communication between the settlement and the people on Earth, with messages transmitting almost instantly.
- Transportation would also be quite simple due to the short distance between the launch site and the settlement, with people being able to get to the settlement in minutes.
- Assembly time and costs would also be low compared to other options due to the proximity to factories and launch sites.
- If the settlement is in a specific orbit of Earth above Low Earth Orbit, it will be protected from radiation and solar storms through the Van Allen Belts.

Negatives include:

- Earth has already been thoroughly researched, so creating a settlement in Earth's orbit would not be very useful.
- Due to the vast amount of space debris in Earth's orbit, the settlement could be impacted and perhaps damaged in its lifetime.

2) The Moon: Benefits include:

- The Moon has been bombarded with meteors and solar wind because it doesn't have an atmosphere or magnetic field, bringing special resources like helium-3 and water ice to the poles, which are very useful for any settlement.
- The Moon isn't researched as much as Earth, and with a settlement being so close with potential surface bases, the scientific understanding of this body could skyrocket.
- There have not been nearly as many artificial satellites around the Moon, causing the amount of space debris to also be much less.
- Although an orbit of the Moon is much further away than Earth, it will still be close enough to limit the cost, transportation, and communication issues.
- A settlement around the Moon can act as a gateway to the rest of the Solar System, as spacecraft need a lot less Delta-V to be able to escape the Moon and Earth's orbit from this location.

Negatives include:

- The Moon's lack of an atmosphere removes its protective blanket, which moderates its temperatures and protects it from meteors and radiation.
- The dark side of the Moon could create some issues in terms of communication and energy generation.

3) Mars: Benefits include:

- It has a protective atmosphere similar to Earth, which could benefit surface bases.
- Natural resources are abundant on Mars' crust and in the atmosphere.
- Phobos and Deimos could be of use to the settlement by providing natural resources and serving as a gateway and travel hub.
- Like the Moon, there is nowhere near as much space debris around Mars compared to Earth.
- Compared to the Moon, Mars has more familiar gravity and day lengths.
- Mars is the least researched option of the three, meaning there is much science to be found with a settlement orbiting this planet.

Negatives include:

- Mars has the largest distance to Earth, meaning that the negatives from the Moon's distance are amplified.
- Surface bases must deal with possible geological activity and the presence of dust storms and other impactful events.

After measuring the pros and cons, we chose the Moon as our location, but we needed to find our specific orbit for our settlement next. The following table identifies and describes each orbit.

TABLE I: Comparison of Lunar Orbits

Name	**Description**	**Pros**	**Cons**
Low Lunar Orbit (LLO)	Circular orbit below 100km altitude, lasting 2 hours.	Best for Moon exploration; efficient for transport.	Least stable; requires high propellant use.
Distant Retrograde Orbit (DRO)	High-altitude orbit opposite the Moon's path.	Highly stable; low fuel use; easy Earth access.	Difficult for Lunar surface access; higher resource/time use.
Near-Rectilinear Halo Orbit (NRHO)	Orbit appearing like a "necklace" hanging from the Moon.	South Pole access; fuel-efficient; good for radiation research.	Virtually no negatives.

After evaluating the table, we decided that the NRHO is clearly the best orbit for a settlement around the Moon. Once we found this out, we discovered that the Lunar Gateway made by NASA will follow the same orbit. This was when the idea clicked to make our settlement an upgrade to the Lunar Gateway, bringing the components needed to support life on a large scale.

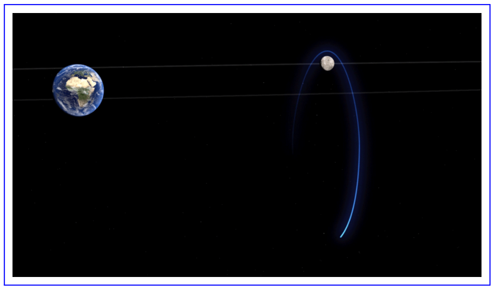


Fig. 5: Gateway's near-rectilinear halo orbit, or NRHO, around the Moon. Source: [5]

B. Structural Assembly and Components

Once we came to this conclusion, we decided the specifics for the new settlement's assembly, which is shown in the table below. For context, the hypothetical complete assembly date of the original Lunar Gateway for this table is June 25th, 2030 (based on estimated Artemis IV launch date and assembly mission which is September, 2028). The assembly for each upgraded component will also be done by the original crew size of four astronauts, giving the realistic estimates shown in the table below. Build Time represents the time it would take to create the new component on Earth. Testing takes place on Earth in a simulated environment. The Logistics Module, Crew and Science Airlock, and Lunar View modules are removed due to automation and an upgraded Orion module. In terms of artificial gravity, each module with this feature has its own gravity rather than the whole settlement. This will be explained in more detail further on.

Name	**Description**	**Build Time**	**Assembly Time**
Water Recycling Loop	A complex loop capable of recycling 98% of clean water in urine and waste.	Begins on June 25th, 2030. Design - 4 months Building - 6 months Testing - 4 months	30 Days to assemble main components (distillation cylinder, separators, pumps) 20 Days to assemble smaller filters, separators, and components 10 Days to test and integrate the system.
Solar Panels for PPE R2	Larger solar panels to provide more energy to the settlement before the tokamak is assembled.	Begins on September 1st, 2030. Design - 6 months Building - 12 months Testing - 6 months	50 Days to assemble and connect the larger solar panels 30 Days to integrate electronics 20 Days to test the system.
Thermolysis Waste Management System	Thermolysis reactor used to treat waste and reuse material	Begins on January 1st, 2031. Design - 6 months Building - 8 months Testing - 6 months	40 Days to install reactor and compressor 30 Days to connect conveyor belt and air streams 20 Days to test and integrate.

Name	**Description**	**Build Time**	**Assembly Time**
H.E.L.P Module A	The first of two modules dedicated to agriculture and life support for a larger crew of 100 astronauts. It has aeroponics and hydroponics systems.	Begins on July 1st, 2032. Design and CAD of frame and structure - 3 months Design of complex agriculture systems - 4 months Digital Testing - 2 months Building structure - 6 months Building agriculture systems - 4 months Combining builds - 3 months Testing structure, subsystems, and connection - 7 months Launch Preparation - 3 months	60 Days to assemble the large structure 40 Days to create the farming systems 20 Days to begin plant growth (plant seeds).
H.E.L.P Module B	The second module is dedicated to growing food in Lunar soil, as well as waste management.	Begins on February 1st, 2033. Design - 12 months Building - 17 months Testing - 10 months Launch preparation - 1 month	75 Days to assemble the larger structure 50 Days for Agriculture integration 25 Days to test and begin systems.
Tokamak Reactor	A nuclear fusion reactor designed to provide half of the energy that the settlement needs using Helium-3. It is designed in a torus.	Begins on January 21st, 2035. Design and simulations - 18 months Building the reactor and needed facilities and subsystems - 24 months Testing - 12 months	120 Days to assemble tokamak torus and main components 90 Days to install subsystems and electricity systems 60 Days to test and begin operation.
HALO R2	A larger version of the original HALO, providing enough living space for 50 astronauts. Includes communications systems to Lunar Bases. Includes artificial gravity.	Begins on August 20th, 2036. Designing and building living spaces - 12 months Designing and building artificial gravity system for large module - 8 months Designing and building thermal, electrical, and communication subsystems - 8 months	60 Days to assemble living quarters in orbit 90 Days to set up gravity system 90 Days to integrate electric, thermal, and communications systems.
Canadarms 4	Multiple highly advanced robotic arms that are capable of carrying large objects. A new and improved 20m range. High precision, and specific sensors compatible with AI models.	Begins on August 29th, 2036. Building structure of arm and joints - 8 months Specific joints, sensors, and components - 10 months	60 Days to assemble the main arms 30 Days to assemble smaller components.
Lunar I-Hab R2	Similar to HALO R2. It can hold fifty people with life support systems. It also has artificial gravity.	Begins on September 18th, 2037. Building the structure of the module - 12 months Building living spaces and life support - 12 months	120 Days to assemble structure (habitats, artificial gravity, radiation protection) 120 Days to assemble subsystems (communications, electrical, thermal).
Orion R2	The improved Orion module has capabilities of Lunar Landings. It also is larger and can carry eight astronauts as well as 10 tons of storage.	Begins on April 6th, 2038. Building the Larger Crew Capsule - 5 months Building the Storage Bay - 6 months Building the Lunar Landing Module - 6 months Ends on September 24th, 2039. Launches on December 6th, 2039.	This module is fully assembled before launch as it is dedicated to travel between the Earth and the Moon.

TABLE II: Assembly Details for All Modules

C. Assembly Material

The primary element of the Lunar Gateway R2's shell requires high durability and low weight to be launched. An alloy that fits these needs is 2195 aluminum. It is a component that is usually associated with modern advanced aerospace due to its high strength (30% increase from 2219, an older alloy used for space exploration) and low density (5% decrease from 2219). This alloy will be used to create the outer cylinders on each primary component. Carbon fiber will be used on the Canadarm 4 and antenna and solar panel brackets for their strength combined with light weight, providing a boost to mobility without deducting strength (specifically Carbon fibre reinforced polymer, which combines carbon fibres and polymer resin). AlSi10Mg (a specialized alloy) will be used to enclose sensitive electronic components due to its thermal and electrical material characteristics, as well as its ability to be 3D printed specifically for complex and small parts. Aluminum alloys 6061 and 7075 are to be used for interior walls in modules with artificial gravity due to flexibility. Tables describing the specifics of each alloy are shown below.

Element	Aluminum 7075 Composition (%)
Aluminum (Al)	87.1 - 91.4
Zinc (Zn)	5.1 - 6.1
Magnesium (Mg)	2.1 - 2.9
Copper (Cu)	1.2 - 2.0
Chromium (Cr)	0.18 - 0.28
Manganese (Mn)	0.3 - 0.9
Silicon (Si)	0.4
Iron (Fe)	0.5
Titanium (Ti)	0.2

TABLE III: Chemical Composition of Aluminum 7075 (Source: ASM Handbook, Vol. 2, 1990) [6].

Element	Aluminum 6061 Composition (%)
Aluminum (Al)	97.9
Silicon (Si)	0.4 - 0.8
Iron (Fe)	0.7
Copper (Cu)	0.15 - 0.4
Manganese (Mn)	0.15 - 0.8
Magnesium (Mg)	1.0 - 1.5
Chromium (Cr)	0.04 - 0.35
Zinc (Zn)	0.25
Titanium (Ti)	0.15

TABLE IV: Chemical Composition of Aluminum 6061 (Source: ASM Handbook, Vol. 2, 1990) [6].

Element	Aluminum 2219 Composition (%)
Aluminum (Al)	93.7 - 95.7
Copper (Cu)	5.8 - 6.8
Manganese (Mn)	0.2
Magnesium (Mg)	1.2
Zinc (Zn)	0.2
Silicon (Si)	0.1
Iron (Fe)	0.2

TABLE V: Chemical Composition of Aluminum 2219 (Source: ASM Handbook, Vol. 2, 1990) [6].

Element	Aluminum 2195 Composition (%)
Aluminum (Al)	95.5 - 97.5
Lithium (Li)	1.9 - 2.5
Copper (Cu)	0.5
Magnesium (Mg)	0.5
Zinc (Zn)	0.2
Iron (Fe)	0.2
Manganese (Mn)	0.1

TABLE VI: Chemical Composition of Aluminum 2195 (Source: ASM Handbook, Vol. 2, 1990) [6].

Element	AlSi10Mg Composition (%)
Aluminum (Al)	85.5 - 94.5
Silicon (Si)	7.0 - 9.0
Magnesium (Mg)	0.3 - 0.9
Iron (Fe)	0.5
Copper (Cu)	0.1
Manganese (Mn)	0.2
Zinc (Zn)	0.1

TABLE VII: Chemical Composition of AlSi10Mg (Source: ASM Handbook, Vol. 2, 1990) [6].

Element	CFRP Composition (%)
Carbon Fiber	55 - 65
Epoxy Resin	30 - 40
Other additives (e.g., curing agents)	5 - 10

TABLE VIII: Chemical Composition of Carbon Fiber Reinforced Polymer (Source: Composite Materials Handbook-17) [7].

D. Debris Shielding

Although the amount of debris orbiting the Moon is significantly less than the Earth, there is still a possibility that an object might collide with the settlement and cause serious damage. For this reason, the walls of the settlement cannot consist of a singular element/material. The first step in finding the layers needed is to identify the possible impacts. Firstly, Gateway R2 uses an NRHO orbit, meaning that it is highly likely (compared to any other Lunar orbit) for an asteroid orbiting the Earth to have contact. Although this is very unlikely, it is still necessary to have precautionary measures. Another possibility is debris from previous Moon missions (such as Artemis missions or assembly missions). The debris from these missions is likely to be aluminum due to its association with aerospace. Finally, Gateway R2's NRHO orbit has a window where it approaches the Moon very closely. This creates a chance for previous satellites in LLO to collide at high speeds. These satellites are also likely to be made of a sort of aluminum, however the speeds will be much higher.

Now that the dangers have been identified, the wall needs to counter each issue with a specific strategy. To counter the issue of small asteroids making contact with the settlement, a 3D printable "space-fabric" is the top layer of the settlement. It is very simple to create, as demonstrated by NASA's JPL, as it can be 3D printed quickly without any human intervention. It is designed to specifically block meteorites and asteroids with its flexibility, following similar themes as chainmail. The debris from previous missions will be addressed with a Whipple Shield, specifically a Multi-Shock Shield (see Figure 6) below the space-fabric. This shield has a thin layer of aluminum above multiple layers of Kevlar and Nextel, and finally a strong layer of carbon fiber composite. This whole shield is designed to disperse the kinetic energy of high-speed impacts, which would be especially useful for artificial space debris. Finally, RCC (reinforced carbon-carbon) is a coating for the rest of the shielding as it is extremely heat resistant (up to 1,650°C or 3,000°F). These three methods will provide certain protection to any dangers in space around the Moon for Gateway R2.

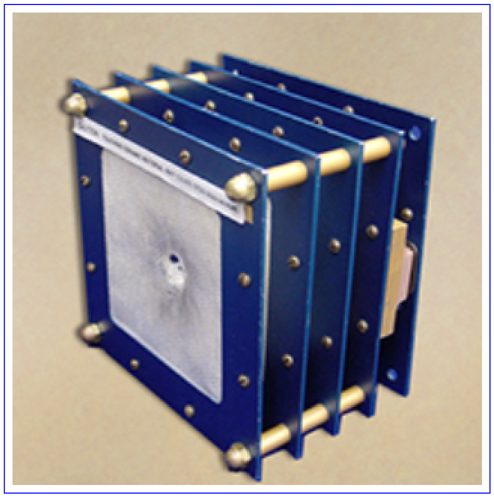


Fig. 6: Multi-shock shield for Gateway R2 Source: [8]

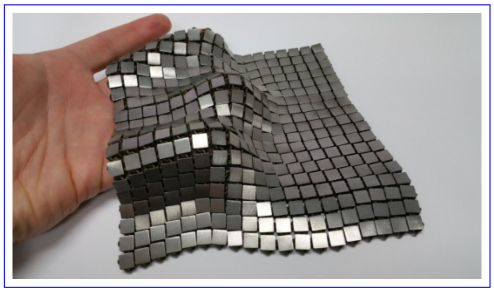


Fig. 7: NASA's Space-fabric from JPL Source: [9]

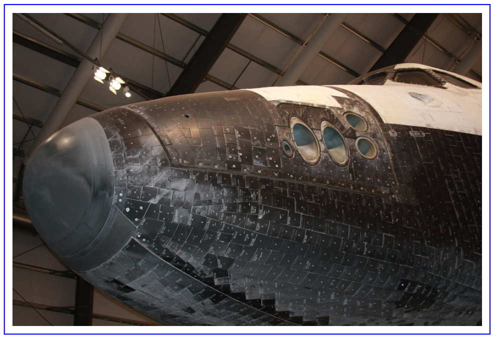


Fig. 8: RCC's application in aerospace on the endeavor Source: [10]

E. Radiation Protection

Now that the settlement has received sufficient protection from the dangers of space, it is time to provide the same service to astronauts and those embarking on missions outside the settlement or bases.

On the Lunar Bases, astronauts will have to walk outdoors for many hours, meaning they need sufficient protection from radiation. This is especially important as the Moon has no atmosphere or magnetic field.

There are two main radiation-related dangers in deep space: Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs). The GCRs specifically alter astronauts' central nervous systems and cognition, as well as cause ionizing radiation effects. According to the Occupational Safety and Health Administration (OSHA), ionizing radiation "can cause damage to the cells and genetic material (i.e., deoxyribonucleic acid, or DNA). If not properly repaired, this damage can result in the death of the cell or potentially harmful changes in the DNA (i.e., mutations)." SEPs, on the other hand, can cause Acute Radiation Syndrome (ARS), which is life-threatening with symptoms such as nausea, vomiting, fatigue, and weakness. Other effects include cognitive decline, increased cancer risk, lung damage, long-term genetic mutations, and other symptoms of radiation poisoning.

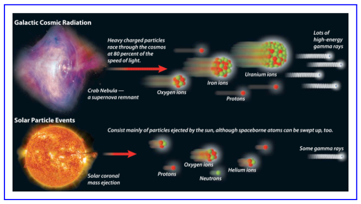

Galactic Cosmic Radiation
Heavy charged particles race through the cosmos at 80 percent of the speed of light.
Lots of high-energy gamma rays
Uranium ions
Iron ions
Oxygen ions
Protons
Crab Nebula — a supernova remnant
Solar Particle Events
Consist mainly of particles ejected by the sun, although spaceborne atoms can be swept up, too.
Some gamma rays
Oxygen ions
Helium ions
Protons
Neutrons
Solar coronal mass ejection

Fig. 9: Galactic cosmic radiation vs solar particle events Source: [11]

Since the specific dangers have been identified, the next step is to find effective and efficient countermeasures.

1) Active Radiation Shielding: Modern research has focused on active radiation shielding as a sought-after solution. This method involves using electromagnetic fields to deflect radiation (charged particles) away from the settlement. Active shielding also prevents secondary particle generation, which can be an issue with passive shielding alone.

One possible implementation is a large and lightweight electrostatically charged structure (such as gossamer membranes) that creates its own field, repelling charged radiation particles. However, minor oscillations may occur due to interactions with the particle flux. This concept has already been tested in recent experiments.

Another method involves deploying multiple superconducting magnets around the settlement, simulating a miniaturized version of Earth's magnetic field. Given that superconducting magnets are already being developed for the energy system of the settlement, this approach is more feasible and stable, especially within artificial gravity environments.

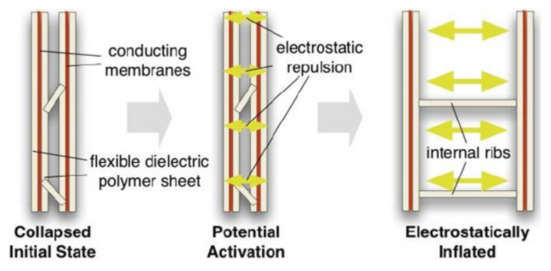

conducting membranes
electrostatic repulsion
flexible dielectric polymer sheet
internal ribs
Collapsed Initial State
Potential Activation
Electrostatically Inflated

Fig. 10: Possible implementation of active radiation protection. Source: [12]

2) Passive Radiation Shielding: Material selection for construction and astronaut suits is also a critical factor in preventing health issues caused by radiation. Ideally, the shielding material should have a low atomic number and low neutron density while also possessing a high electron density.

Hydrogen fits these criteria well, but its instability makes it unsuitable. A reliable alternative is aluminum alloys, which are already used in constructing various parts of the settlement. However, for Lunar Bases, a more sustainable solution exists—Lunar regolith. This material shares the desired radiation-protective properties and is abundant on the Moon's surface. Coating bases with Lunar regolith provides an additional layer of shielding.

3) Astronaut Radiation Protection Suits: Astronauts venturing outside the settlement need dedicated radiation protection. A viable solution is a vest similar to the AstroRad radiation protection vest. This vest is engineered to provide mobility while incorporating a dense, low-Z material (high in hydrogen) to mitigate radiation exposure.

The AstroRad vest, constructed from High-Density Polyethylene in a hexagonal configuration, offers both flexibility and enhanced protection against SEPs. Additionally, it shields vital organs and protects stem cells, reducing the risk of radiation-induced cancers.

Fig. 11: AstroRad experimental vest on Artemis 1 Source: [13]

4) Conclusion: Radiation poses a significant health risk for astronauts. The combined use of active and passive shielding ensures effective protection. Active shielding (electromagnetic deflection) is ideal for the settlement, while passive shielding (aluminum alloys, Lunar regolith, and radiation vests) provides additional safety for astronauts on missions. These measures are tailored specifically to counteract the unique radiation environment of the Moon and its bases.

F. Gravity Generation

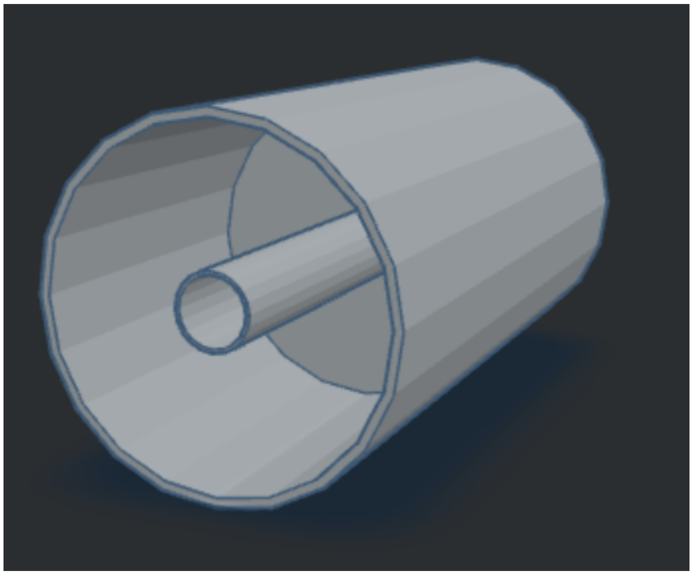


Fig. 12: Diagram visualizing unique artificial gravity system with simplified H.E.L.P Module A, with tunnel and no walls on the side. Source: Primary

Since our settlement is an upgrade to the Lunar Gateway, it is important to acknowledge that the foundation to the settlement has already been provided through the layout. This is why the group decided to keep the same layout, which means that a ring or cylindrical structure used for most other hypothetical space settlements to generate gravity is not possible. Specifically, one large ring is not possible. This led to the creative conclusion of creating a separate gravity ring for each module, preserving the layout yet adding the necessity of gravity.

Gravity is necessary due to the drastic health effects of zero gravity on the human body. Using NASA's Human Research Program (HRP), many adverse health effects from zero gravity have been identified. The most common effect of zero gravity on the body is the loss of mineral density (1-1.5% a month) on weight-bearing bones. This loss is very difficult to fix, even with utmost rehabilitation efforts. Another common effect of zero gravity is losing muscle mass exponentially faster than on Earth, especially without a nutritious diet and exercise routine. It is unfair to expect these two traits in every person in the settlement, so it is necessary to reduce these expectations. More issues include body fluids traveling upwards causing vision problems, an increased risk of kidney stones, and a loss of calcium from bones. With all of these symptoms among many others, it is clear that artificial gravity must be implemented on the Gateway R2.

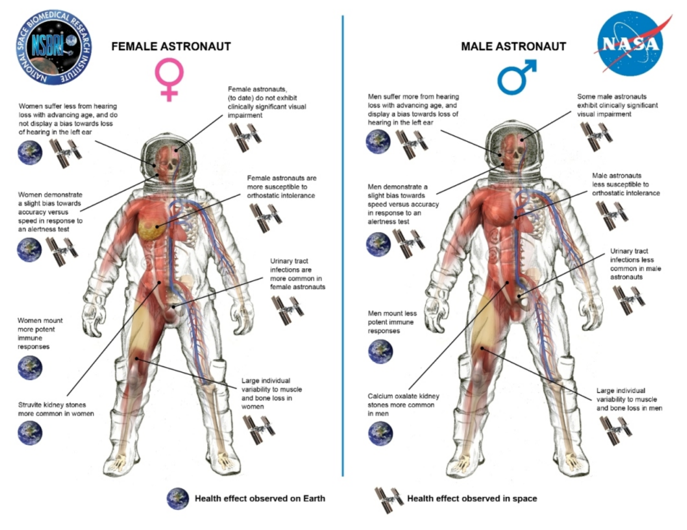

FEMALE ASTRONAUT
Women suffer less from hearing loss with advancing age, and do not display a bias towards loss of hearing in the left ear
Female astronauts, (to date) do not exhibit clinically significant visual impairment
Female astronauts are more susceptible to orthostatic intolerance
Women demonstrate a slight bias towards accuracy versus speed in response to an alertness test
Urinary tract infections are more common in female astronauts
Women mount more potent immune responses
Large individual variability to muscle and bone loss in women
Struvite kidney stones more common in women
MALE ASTRONAUT
Men suffer more from hearing loss with advancing age, and display a bias towards loss of hearing in the left ear
Some male astronauts exhibit clinically significant visual impairment
Male astronauts less susceptible to orthostatic intolerance
Men demonstrate a slight bias towards speed versus accuracy in response to an alertness test
Urinary tract infections less common in male astronauts
Men mount less potent immune responses
Calcium oxalate kidney stones more common in men
Large individual variability to muscle and bone loss in men
Health effect observed on Earth
Health effect observed in space

Fig. 13: Effects of zero gravity on male and female astronauts. Source: [14]

The modules will use centrifugal force to create artificial gravity matching 1G of force, making it as close to Earth's gravity as possible. The Orion R2 and PPE R2 modules will not receive artificial gravity due to the lack of necessity. The Orion R2 does not need gravity as it is mainly used for travelling between the Earth, the Gateway R2, and the Lunar Bases, meaning there will not be much time spent on this module. The PPE R2 module is also not used much as it is mainly automated. The rest of the modules are constantly used by the population, meaning they need gravity. Each module is cylindrical in shape, and they rotate individually. To better understand the gravity generation, see Figure 12, as it is quite confusing to understand the two tunnels and where gravity is and is not. The tunnel through the centre is used to enter the modules.

Module	**Specifications**	**Calculations**
H.E.L.P Module A	The H.E.L.P Module A has dimensions of 20m length and 31.4m circumference, with an estimated mass of about 70,000kg using the density of the aluminum alloys in the walls and the aeroponics and hydroponics systems inside.	To calculate the tangential velocity of this module to create 1G (9.81m/s) of centrifugal acceleration, the following equation was used with the radius of 5m: $$v = \sqrt{9.81 \times 5} = \sqrt{49.05} \tag{1}$$ Evaluating this square root, the velocity is approximately 7m/s. Converting this into RPM uses the formula: $$RPM = \frac{v}{2\pi r} \times 60 \tag{2}$$ Solving this using the tangential velocity and the radius of 5.2m gives an RPM of about 13.1. It is also important to calculate the force required to spin this module. The formula needed to calculate this is: $$F = \frac{mv^2}{r} \tag{3}$$ Solving this formula with the estimated mass of about 100,000kg gives a force requirement of about 980,000 newtons, which is crucial in meeting the energy needs to rotate this module.
H.E.L.P Module B	H.E.L.P Module B has a similar shape (but larger) to H.E.L.P Module A. It has more complicated systems and a 22m length with the same circumference. Using these factors, its estimated mass is about 80,000kg.	Since this module has the same radius as H.E.L.P Module A, its calculations for RPM remain the same, which are: To calculate the tangential velocity of this module to create 1G (9.81m/s) of centrifugal acceleration, the following equation was used with the radius of 5m: $$v = \sqrt{9.81 \times 5} = \sqrt{49.05} \tag{4}$$ Evaluating this square root, the velocity is approximately 7m/s. Converting this into RPM uses the formula: $$RPM = \frac{v}{2\pi r} \times 60 \tag{5}$$ Solving this using the tangential velocity and the radius of 5m gives an RPM of about 13.4. Like H.E.L.P Module A, It is also important to calculate the force required to spin this module. The formula needed to calculate this is: $$F = \frac{mv^2}{r} \tag{6}$$ Solving this formula with the estimated mass of about 79,200kg gives a force requirement of about 775,000 newtons, which is crucial in meeting the energy needs to rotate this module, especially as it is more than the previous one.
Lunar I-Hab R2	This module is one of two modules, and it has life support systems and habitation areas for 50 astronauts. Its radius is 5.2m. Its length is 15m. It has many life support systems. The mass of this module is about 100,000kg.	To calculate the tangential velocity of this module to create 1G (9.81m/1) of centrifugal acceleration, the following equation was used with the radius of 5.2m: $$v = \sqrt{9.81 \times 5.2} = \sqrt{51.01} \tag{7}$$ Evaluating this square root, the velocity is approximately 7m/s. Converting this into RPM uses the formula: $$RPM = \frac{v}{2\pi r} \times 60 \tag{8}$$ Solving this using the tangential velocity and the radius of 5m gives an RPM of about 13.4. It is also important to calculate the force required to spin this module. The formula needed to calculate this is: $$F = \frac{mv^2}{r} \tag{9}$$ Solving this formula with the estimated mass of about 70,800kg gives a force requirement of about 695,000 newtons, which is crucial in meeting the energy needs to rotate this module.

Module	**Specifications**	**Calculations**
HALO R2	This module is one of two modules dedicated to life support and habitation for astronauts. It is large enough to support 50 astronauts. Its specific dimensions are: a radius of 4.4m and a length of 20.6m. It has many complex systems adding a lot of mass, with an estimated total of 120,000kg.	To calculate the tangential velocity of this module to create 1G (9.81m/s) of centrifugal acceleration, the following equation was used with the radius of 4.4m: $$v = \sqrt{9.81 \times 4.4} = \sqrt{43.164} \quad (10)$$ Evaluating this square root, the velocity is approximately 6.57m/s. Converting this into RPM uses the formula: $$RPM = \frac{v}{2\pi r} \times 60 \quad (11)$$ Solving this using the tangential velocity and the radius of 4.4m gives an RPM of about 14.3. It is also important to calculate the force required to spin this module. The formula needed to calculate this is: $$F = \frac{mv^2}{r} \quad (12)$$ Solving this formula with the estimated mass of about 120,000kg gives a force requirement of about 1,180,000 newtons, which is crucial in meeting the energy needs to rotate this module.

TABLE IX: Specifications related to gravity calculations, with calculations and formula in the right-most column.

G. Propulsion Systems

Since this orbit is in an NRHO orbit of the Moon, it needs engines to stay in a stable orbit. These engines must be sustainable and quiet to promote the self-sustaining nature of the settlement and not be a hindrance to the astronauts.

After conducting some research, a clear candidate revealed itself. The DGEN380 Aero-Propulsion Research Turbofan (DART) is a small jet engine currently being tested by NASA at the Aero-Acoustic Propulsion Laboratory at NASA's Glenn Research Center in Cleveland. During testing for this engine, it has been noticed that it is extremely quiet, even in soundproof environments. This means that implementing this engine would reduce vibrations in the settlement during orbit corrections due to its quietness. Its lack of noice comes from being made of a material that absorbs sound rather than reflecting it, similar to soundproof rooms with acoustic panelling. It is also small, measuring 1.3 metres, meaning there are not many issues regarding shipping, assembly, or views. This engine also meets sustainability requirements as it is known for being much more fuel efficient compared to other engines. However, there is a large roadblock to using this engine. Since it is a jet engine, it will not be able to function in space without modifications. The most efficient way to provide an oxidizer to this engine would be to make it function similarly to SABRE engines. SABRE engines are designed to switch between two modes. One functions in the Earth's atmosphere and works as a regular jet engine, collecting the ambient air and compressing it to power the engine. The second mode is designed to function in deep space, using liquid oxidizer to function as a normal rocket engine. The goal for Gateway R2 would be to modify the DART engines to combine liquid oxidizer tanks with the jet engine and produce a sustainable, quiet, space-efficient, and powerful engine that meets all requirements for both the settlement and the Orion R2 lander and transporter between the Earth and the Moon. It would be specifically effective for the Orion R2 ship since the jet engines can function as they normally would on the Earth during launch. In terms of resource sustainability, there are many materials containing Oxygen in Lunar Regolith, and the Oxygen has already been previously extracted from the soil by NASA. These can be used to fill the tanks for these engines.

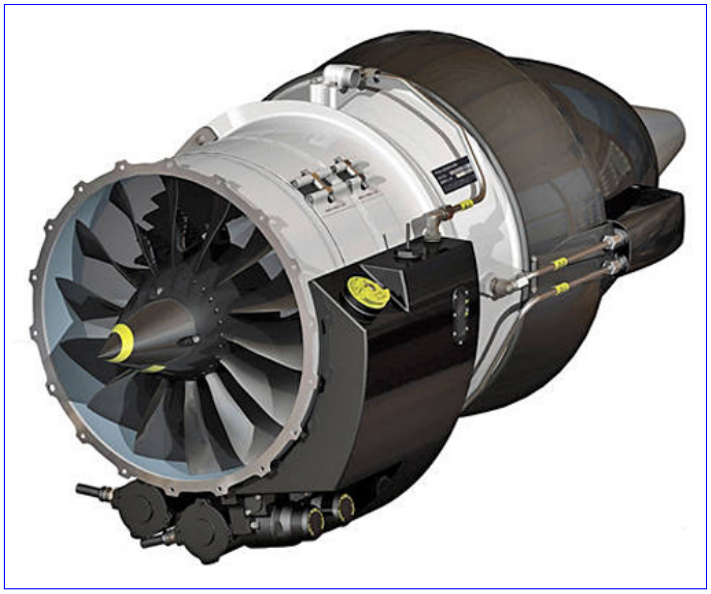


Fig. 14: Digital image depicting the DGEN380 Aero-Propulsion Research Turbofan (DART) Source: [15]

H. Canadarm 4 Model

When considering automation for the settlement, Canadarm 4 felt like it was not enough to maintain the entire settlement. This is why Canadarm 4 was transformed into multiple smaller versions of the same arm that can maintain the entire settlement from the outside, reducing the need for space walks and other risky maintenance missions.

This led to the creation of the Canadarm 4 model. It is a compact robotic arm created with Arduino. It was created to provide a scale version and prototype of the actual Canadarm 4. This arm has 3 joints (the shoulder or main arm, elbow, and wrist) which are all controlled by servos. The shoulder is controlled by a 20kg servo with high torque, as it is designed to be the main joint for the entire arm. The elbow is controlled by a high speed servo, as well as the wrist, as they do not need as much torque. There is a gripper micro servo that controls the hand that is able to grab items. The arm itself rotates from the base, which is controlled by a high torque servo (not as high as the shoulder), and spins a full 360 degrees. The whole arm is controlled by a miniature version of the arm made of potentiometers. This miniature arm uses the potentiometers and maps their values onto the servos to mirror both arms. On the actual Canadarm 4, it would be automatically controlled by AI to reduce human involvement and increase leisure time. The code for the robot and some multimedia is shown below. Credits for the design and code go to Kelton from Build Some Stuff.

After creating this robot, there was not much time left to refine it and add upgrades. Some possible new improvements could be to add sensors and more heads other than the gripper head. A possible upgrade could be to add a drill head and camera for automation and maintenance. Sensors could include thermal sensors or distance sensors.

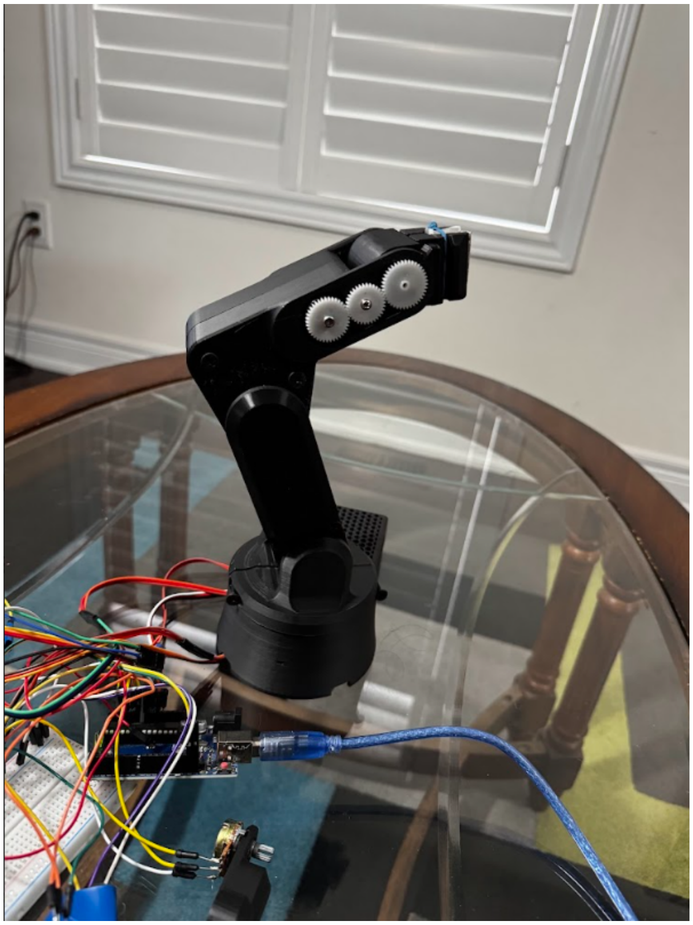


Fig. 15: A picture of the completed Canadarm 4 model, more multimedia can be found on the Google Drive folder here Source: Primary

IV. SUSTAINING LIFE

Fig. 16: Source: [16]

1) Food and Water:

Food and water are the primary aspects covered in the first few pages of the Sustaining Life section. The sources of both of these necessary resources are described here.

2) Artificial Atmosphere:

This section covers the specifics of the artificial atmosphere, as well as its source. It goes in depth about these subsections, with exact information and sources that provide realism to the entire part.

3) Waste Management:

The third section describes Gateway R2's complete waste management system. Thermolysis is introduced along with its connections to the rest of the settlement's primary systems. The feeding system is also described.

4) Electricity and Thermal:

The methods of generating electricity are explained. Larger Solar Panels and a Tokamak reactor increase energy output, connecting to the heating systems.

A. Hydration

1) Shipment: Water is one of the most important resources a settlement needs, which is why it must come from the moon, as it cannot be artificial. Most water gets recycled through a loop described later, but this water needs to come from somewhere, which is where the shipment system comes in. Water will be mined on the moon, as recently it has been discovered that 600 billion kilograms of frozen water could be on the moon's poles. This ice gets extracted at Base Excellence and Base Persistence. These bases are also where water shipping takes place. The North and South bases will send 10 Contingency Water Containers (CWCs) to the settlement using skyhooks every day through autonomous storage spacecraft. Each CWC contains 50 L of water. Skyhooks are tethers placed in the orbit of a celestial object (in this case, the moon) that use a counterweight and some engines (ion engines for our settlement) to maintain enough momentum to slingshot the payload to a specified destination, which is our settlement. The timing is crucial and managed by computers at the nearest lunar base. The velocity gained is related to the rotational speed of the skyhook and the radius of its orbit. The formula for calculating the tangential velocity in a circular orbit is

$$v = \omega r \tag{13}$$

where v is the tangential velocity, omega is the angular velocity (related to the rotational speed of the skyhook), and r is the radius of the orbit. The skyhooks will be at an angle of about 45º (increasing in altitude and to the right) from the north and south bases, collecting and receiving storage ships to maintain momentum. About half of a kiloliter will be shipped to the settlement every hour, which lasts longer using our water recycling loop. Below is a diagram portraying the skyhook system.

Fig. 17: An image of a modern CWC. Source: [17]

2) Recycling Loops: The water received through skyhooks is still not enough for the massive usage of our settlement, including agriculture, drinking, waste management, and cleaning. This water is recycled in our settlement using one efficient closed loop in a similar system to the ISS. We used a similar water recycling system because the ISS has a very efficient and successful loop incorporated, with a 98% reusing rate. We feel the system used in the ISS could shrink into one closed loop. The loop distills urine from its specialized input, and after that, it receives the rest of the wastewater input and flows through multiple tanks to make the water drinkable once again. There are 12 unique parts in the whole loop. The pipes are 10 cm in radius. The clean water is split and distributed over the settlement after clearing the loop. A table describing these parts is below.

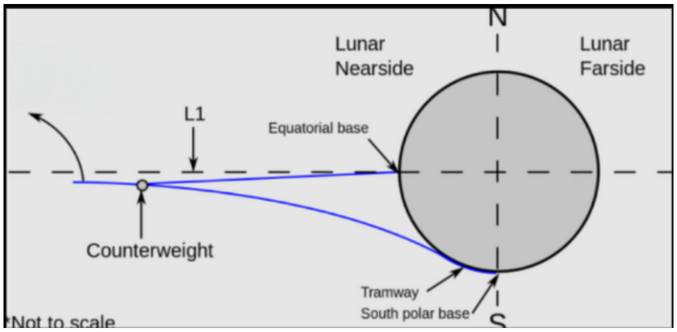


Fig. 18: A diagram showing the positions of skyhooks over Lunar Bases. Source: [18]

Parts	**Purpose**	**Measurements**
Distillation Cylinder	The distillation cylinder is a component that heats up and distills urine in this loop, and its output is distilled urine. It receives filtered urine from the filter tank.	The volume is 15710 liters, with a 0.75 meter radius and 5 meter height.
Separator	The separator removes water from the purge gasses that have been extracted from the distillation cylinder. The water that has been separated is pumped back into the distillation cylinder. The separator works by taking advantage of the artificial gravity and having the higher density (water) go “down.”	The volume of the separator is 6160 liters, with a 0.5m radius and 4m height.
Fluid Pumps	The fluid pumps transport the fluids to different parts of the loop. The first pump transports urine to the distillation cylinder. The second group of two pumps transports wastewater from the distillation cylinder to the filter tank. The final pump transports the output of the distillation assembly to the air separator. These pumps are external gear positive displacement pumps. They rotate gears to create a liquid seal and a vacuum at the inlet of the pump. Two gears are in the center of the pump, and constantly spinning. The water flows into the gears, around the top/bottom, and is forced out under pressure.	The whole line of pumps is 5m long. Each gear has a radius of 20cm and 48 teeth. The input and output tunnels have a radius of 5cm.
Purge Pump	Purge pumps are very similar to the fluid pumps, but with a different purpose. The purge pumps remove gasses from the distillation cylinder and transport them to the separator. The purge pumps are also external gear pumps, and work the same way. Coolant (ammonia) is added in these purge pumps to condense the gasses before reaching the separator.	The measurements of the purge pumps are the same as the measurements of the fluid pumps.
Filter Tank	The filter tank’s main purpose is to accumulate and store brine from urine to prevent it from contaminating the rest of the system. The brine is separated from the urine in the distillation cylinder, but it is collected and stored for disposal in the filter tank. The clean water that is collected in this tank is pumped back into the distillation cylinder. The brine is sent for disposal from this tank.	The radius of this tank is 0.7m and the height is 3m. The volume of this tank is 4620 L.
Air Separator	The air separator receives urine distillate from the previous group of parts. The gasses are extracted and sent to other parts of the settlement once filtered. The air separator will use a centrifugal system.	The filter has a radius of 20 centimetres and a height of 100 centimetres.
Particular Filter	This filter removes sediment and small suspended particles. They are made of thermally-bonded microfiber polypropylene to remove these particulates.	Each entrance pipe has a radius of 10cm. The filter itself is 15 cm by 30cm.
Dissolved-Material Filters	These filters remove salts and organics. They will use adsorption. The particles or contaminants (organic material and salt) become attracted to and attached to the surface or larger objects, taking advantage of energy differences and electrical forces to act as a “magnet.” Activated carbon will be used to attract dissolved materials.	Each entrance pipe also has a radius of 10cm. The filters are 15 cm by 25cm.
Preheater	The preheater’s only purpose is to heat water before the next component. It works simply by heating up metal using electricity and this metal heats up the surrounding liquid in the pipe to 275 ℃.	Is place inside the main pipe which has a diameter of 10cm. The metal has a length of 30cm.
Reactor	The reactor is placed in the loop to remove any remaining organics in the water. It does this via oxidation. The heated up water from the preheater enters this part which is where the organics are oxidized in the heat of the reactor.	The reactor has a height of 1m and a radius of 20cm.
Oxygen Separator	This separator works similarly to the previous air-water separator, but it only separates the gas oxygen that is remaining.	It has a radius of 20cm and a height of 50cm.
Byproduct Remover	This final component removes byproducts and completely cleans the water. It is a common water filter, called an ion exchange bed. They work by having cation and anion resin mixed together in a single tank, and as water flows through, ions are exchanged and the water is “polished.”	The height is 1m and the radius is 25cm.

TABLE X: All individual components of the water recycling loop, with descriptions and measurements.

B. Food

1) Hydroponics: Hydroponics are revolutionizing the way we grow crops and plants. By taking out the unnecessary use of soil, we can save so much space and effort by using water instead of soil. Hydroponics are a core pillar of our settlement. To ensure the utmost health in outer space, part of our nutrition will come from hydroponics. As we can fine-tune so many of the conditions of growing, the plants grow faster and healthier due to the significant benefits that come from hydroponics. Hydroponics comes with the use of Perlite, Perlite is a critical resource for plants. If you ever bring home potting soil, you will probably see little white rocks, those are perlite! Perlite acts as an "air-creator" for the roots of plants. This ensures that plants can get the dioxygen they need. The hydroponics are organized in shelves shown in the earlier diagram, where they are stacked on top of each other to the ceiling. Common veggies such as tomatoes, cucumbers, etc. thrive in being grown by hydroponics, others can work but they will not be as efficient. This brings us to our second method of crop production, aeroponics.

2) Aeroponics: Aeroponics is a groundbreaking method of farming which minimizes the infrastructure and materials required for sustainable agriculture. They allow plants to thrive without the use of soil, and minimal usage of water. This makes aeroponics a much more space-efficient method of farming, a key factor in making our settlement sustainable. Although these roots may be naked, that doesn't mean they don't grow. In fact, plants grown with aeroponics have been shown to yield 30% more produce and grow 3 times faster than those raised with traditional techniques, raising the roof for their counterparts. Aeroponics work by having nutrient-rich water misted over plant leaves. The plants are kept under UV light to allow for photosynthesis to take place, resulting in the plants receiving all the nutrients and chemicals needed to survive. This method allows the plants to grow with nearly 95% less irrigation than conventional methods. Essentially any plant can be grown with aeroponics, even root-based crops, which cannot be done with hydroponics.

3) Lunar Regolith: Soil, something that we take for granted here on Earth, is an incredibly valuable resource in space. It allows for the growth of plants and is the backbone of life on Earth. In our settlement, the closest alternative we have is lunar regolith, which is essentially the soil of the moon. Lunar regolith is a thick layer of rock material that covers the entire surface of the moon. It is the result of the continuous impact of meteoroids and charged particles from the sun onto the moon. The lunar regolith is mostly composed of rock chips and mineral fragments. As a result, the lunar regolith has an abundance of essential minerals that are necessary for life. However, lunar regolith lacks in certain nutrients such as nitrogen, and it becomes tightly compacted when wet, which makes it difficult for plant roots to flourish.

How it Works:
All of this begs the question of whether plants can be grown in lunar soil or not. Well, using the help of biochar, which is a type of organic matter outputted by our bioreactor, it can be possible. Biochar has several properties and nutrients that lunar regolith is lacking which are needed for growing plants. For example, biochar provides nitrogen, phosphorus, and potassium, which are all nutrients that lunar regolith usually lacks in. A key property of biochar which makes it useful is that it increases the water-holding capacity of the substance it is in. This is exactly what is necessary for growing in lunar regolith, as the regolith becomes tightly compacted when exposed to water. This means it has a low water holding capacity, which biochar will fix, allowing for plant roots to flourish. Since this is a completely new method of growing, we will conduct an experiment using lunar regolith and biochar to see if plants can actually grow in it.

Now we are going to go over why we chose each type of food for its' specified method of growing. We chose the foods for hydroponics and aeroponics based on previous research. The research found that these specific foods work well with the desired method of growing. Moving on to lunar soil, we first chose leafy greens as we are growing lettuce for our experiment consisting of a lunar soil simulant. The rest of the things we chose for lunar soil are grains and things that have roots. This is because of the fact that these types of plants grow well in normal soil, which we can emulate using lunar soil.

Now, let's go over where specific plants will be placed for the hydroponics, aeroponics, and lunar soil growing areas of our settlement. First off, on the leftmost side of the hydroponics section, we will grow mint, chives, herbs, and thyme, then in the next section there will be kale and bok choy, then there will be radishes and celery, and on the rightmost side, there will be peppers and rosemary that will be taken care of by the crew. Next, for the aeroponics section going counter-clockwise, there will be tomatoes and zucchini, berries, melons/watermelons, tomatoes and eggplants, garlic, tomatoes and watermelons, berries, melons zucchini, garlic, eggplants and zucchini, zucchini and melons/watermelons, tomatoes and berries, garlic, berries, and lastly tomatoes. Finally, for the lunar soil section going downwards, there will be leafy greens and cabbage, cauliflower and broccoli, onions and ginger, potatoes and lentils, chickpeas and soybean, wheat and quinoa, nuts and olives, ginger and avocados, wheat and soybean, quinoa and chickpeas, cabbage and broccoli, avocados and olives, cauliflower and potatoes, onions and lentils, and lastly leafy greens.

For hydroponics, according to the University of Minnesota, we need "a container, water, a way to anchor the plants, nutrients and a light source." We have containers and water, we need a way to anchor the plants. As a part of the robots we are going to build for automation, we will create a system to anchor the plants. Moving on to nutrients, we are using nutrient-rich water. For this, we need water with Nitrogen, Phosphorus, Potassium, Sulfur, Magnesium, Calcium, Hydrogen, Iron, Zinc, Boron, Copper, Chlorine, and Manganese. For this, we will have mixes of the required nutrients and then pour

Hydroponics	Aeroponics	Lunar Soil
• Peppers • Celery • Kale • Mint • Chives • Herbs • Radishes • Bok Choy • Rosemary • Thyme • Cucumber	• Everyday Fruits • Tomatoes • Eggplants • Melons • Berries • Zucchini • Garlic	• Leafy Greens • Cabbage • Cauliflower • Onions • Ginger • Potatoes • Chickpeas • Lentils • Wheat • Nuts • Quinoa • Soybean • Broccoli • Olives • Avocados

TABLE XI: Lists of food growing distribution.

them into the water which we use for hydroponics. For our light source, we are using full-spectrum lamps. Since they can cover the entire spectrum of light, they can emulate UV light which is crucial for us. Moving on to techniques for aeroponics and lunar soil…

For aeroponics, the necessary equipment is mostly the same as hydroponics. Both require the same nutrient rich water and lights. Aeroponics also need mister heads and tubing to deliver the water, which will be integrated into our robots. Lastly, they require towers in which the plants will be placed, which can be made of a composite plastic material and manufactured using 3D printing techniques. Growing with lunar regolith involves the same basic equipment as growing with normal soil. This includes potting beds, the soil itself, normal water, lights, and biochar. The soil and water will be collected from our lunar bases and the lights are the same full-spectrum lights. Lastly, the potting beds are made of the same composite material and the biochar will be from our reactor.

As a result of the countless jobs that must be fulfilled in a space settlement, automation is essential to reduce the workload and stress on the crew. Automating our hydroponics and lunar soil growing areas will involve the use of robots, cameras, and sensors that facilitate all agricultural processes. Initially, when a space is free in the lunar soil or hydroponics growing areas a robot will plant a seed using specialized grippers to ensure precision. Water will be given to the lunar soil crops using the same robots at constant intervals. Cameras will then notify the robots of when plants have become ripe and ready to harvest. This can be done through the use of AI models, which will be trained to identify what each specific type of plant looks like when it is ripe. For extra quality assurance, growing areas will also include infrared sensors that detect and notify the crew of potential issues in the plants. Finally, the same robots will harvest the crops and drop them off to a conveyor system. This system is like the feeding system of the bioreactor, just in reverse, where plants and their seeds will be sorted and sent to cooking areas or back to the H.E.L.P. modules.

The automation of the aeroponics growing areas involves all the same procedures, however the design of the robots will be different. The robots used to automate the aeroponics growing areas will have a ring design to support the vertical setup of these growing methods. These ring-shaped robots will move up and down the columns of the aeroponics crops and provide all the essential facilities they need. This includes planting new seeds, harvesting ripe plants, and giving them water. They will also have infrared sensors telling the crew when something goes wrong and cameras to determine when to harvest. When it is time to harvest, the plants and their seeds will be dropped down the column on which they are growing and sent to the same conveyor system, which will sort and transport the plants to wherever they're needed.

4) Nutrition: To go scratch the surface of our nutrition, we need to talk about the biggest thing; calories. The average human needs 2000 calories per day, so that is our goal for most meals. Of course, this depends on the person, but as a general rule, we use 2000. We will be doing a 45-30-25 split. This means that 45% of calories will come from carbohydrates, 30% of calories will come from protein and 25% of calories will come from healthy fats. Our macronutrient goals are directly derived from our calorie split. We aim for 225g of Carbohydrates, 150g of Protein, and 55g of healthy Fats. Our macronutrients will mainly come from things we can grow. For carbs, we have things such as bread and chickpea pasta. For protein, we will have lentils, chickpeas, quinoa, and nuts. Lastly, for healthy fats, we will have nuts, avocado, olive oil, and soybeans. There are many vitamins necessary for human survival. These include: Vitamins A, C, D, E, K, and B vitamins (thiamine, riboflavin, niacin, pantothenic acid, biotin, B6, B12 and folate) These vitamins help resist infections, help your nerves stay healthy, help your body in absorbing energy from foods. You also need minerals which are: calcium, phosphorus, potassium, sodium, chloride, magnesium, iron, zinc, iodine, sulfur, cobalt, copper, fluoride, manganese, and selenium. The minerals ensure that everything in your body is functioning properly, from your heart to your lungs and even your muscles. In our meals, we need to address three prevalent issues in modern nutrition. They are quick-absorption meals and lack of dietary fiber in diets. Beginning with absorption speeds, a meal must have slow absorption because if it does not, using data from the real world, spikes in blood glucose and insulin are prone to occur. A solution to this issue is eating foods that gradually release glucose and insulin into the bloodstream rather than in spikes. These foods are usually rich in carbohydrates (whole grains, legumes, vegetables, fruit), protein (soybeans, chickpeas, nuts), healthy fats (avocado, soybeans), or fiber. In summary, combine macronutrients and stick to high-fiber foods. Dietary fibers also solve other issues, like feeding the gut microbiome. The H.E.L.P Modules must create fiber-rich foods like fruits and vegetables. The solution

Meal (time)	Dish	Ingredients	Nutrition
Breakfast (8:00)	Avocado Kale Toast with Radish and Herb Smoothie	1 slice whole grain bread, ½ avocado, 1 cup kale, 1 tbsp chives, 1 cup radish and mint smoothie (radishes, mint, cucumber water)	Calories: 450 kcal, Carbohydrates: 55g, Protein: 9g, Fats: 18g, Vitamin C: 80 mg, Fiber: 10g
Morning Snack (11:00)	Garlic Mushroom Sauté	1 cup mushrooms, 1 clove garlic, 1 tsp olive oil, fresh thyme/rosemary	Calories: 100kcal, Carbohydrates: 5g, Protein: 3g, Fats: 6g, Vitamin D: 10mg, Fiber: 2g
Lunch (13:00)	Chickpea, Quinoa, and Grilled Vegetable Bowl	½ cup chickpeas, ½ cup quinoa, grilled vegetables (eggplant, zucchini, tomatoes), ½ cup broccoli, 1 tbsp olive oil	Calories: 600 kcal, Carbohydrates: 75g, Protein: 20g, Fats: 18g, Vitamin C: 120 mg , Iron: 4 mg
Afternoon Snack (16:00)	Nut and Berry Mix with Cucumber Ginger Water	¼ cup mixed nuts, ½ cup mixed berries, cucumber slices infused with ginger water	Calories: 300 kcal, Carbohydrates: 20g, Protein: 7g, Fats: 22g, Vitamin E: 6 mg, Fiber: 5g
Dinner (19:00)	Soybean and Potato Curry with Steamed Bok Choy	½ cup soybeans, 1 potato, 1 cup bok choy, ¼ soy milk, 1 onion, 1 tsp ginger, 2 garlic cloves, 1 tsp olive oil	Calories: 650 kcal, Carbohydrates: 75g, Protein: 25g, Fats: 18g, Vitamin A: 500 µg, Iron: 5 mg

TABLE XII: A possible Gateway R2 meal plan during the first months of operation with the H.E.L.P Modules

to these two issues is to increase the production of foods that contain dietary fibers and macronutrients. Another significant issue prevalent in current society is the presence of allergies. Many of our meals include foods like nuts and soy that can cause deadly allergic reactions. We want to avoid this so we will grow alternatives for those in our settlement with allergies. These alternatives need similar nutritional properties, such as slow absorption, rich in dietary fibers and protein, rich in healthy fats, and finally rich in Omega-3. Following these criteria, we conclude that the alternative food is plant seeds or cooking in seed oil. Specifically, pumpkin and sunflower seeds. Moving to essential amino acids, we will eat nuts, grains, and mushrooms (which have all of the essential amino acids!). Amino acids are valuable to us to build muscle, grow and repair muscle, create hormones, boost our immune system (help combat sickness, promote healing when unwell or injured), create brain chemicals (which affects mood, appetite and sleep). Amino acids are essential to survival, to ensure we have access to these acids is essential for a healthy survival in the environment which is space.

5) Lettuce Experiment: This experiment involves growing lettuce seeds in two different types of soil. The soil types include nutrient-rich soil from the Greater Toronto Area and a lunar regolith simulant fertilized with biochar. We chose to grow lettuce for multiple reasons. Firstly, they grow very fast and are able to provide a large amount of data in the time we have. Secondly, lettuce has specific requirements in soil, which is why they are a good test for our three types of soil. The soil needs to be nutrient-rich and mainly needs to have high moisture. Since lunar soil has most of the nutrients of regular soil, the lettuce won't have a problem there. But lunar soil has properties that don't let it hold water very well which might cause an issue in growing lettuce. That's why biochar is used, to provide properties to the lunar soil to be able to hold water more effectively compared to lunar soil without biochar.

Overall, this experiment will test the growing capabilities of these soils throughout several days to help us learn about the use of biochar in day-to-day growing methods. The objective of this experiment was to analyze the difference between plant growth in normal soil, lunar soil simulant, and lunar soil simulant with biochar. We wanted to see if plant growth in normal soil and lunar soil simulant with biochar is comparable and if the plants grow better in one environment than the other. This experiment will also show what kind of farming techniques and water quantity are needed to grow in lunar soil. All lunar regolith extracted for our settlement will be shipped from Base Persistence after being mined in the South Pole Aitken Basin. The properties of the regolith in this specific basin will be replicated in the simulant. One such property is being rich in iron (II) oxide. Iron in soil as a micronutrient plays a large role in allowing photosynthesis and synthesis of chlorophyll to occur. The soil in this site has a high fidelity and a maximum grain size of about 2mm, although most regolith is dust-like with a very fine consistency. We replicated all of these properties. We chose baby leaf lettuce as it grows the fastest and will give us the most data in the amount of time we have to conduct the experiment. We predict that normal soil will germinate the quickest, have the most leaves, and grow the tallest because it is the standard. However, we hope that the lunar regolith simulant with biochar has similar growth as it is what we are using in our space settlement. Since our simulant will be of lower quality, it won't have a good level of growth. We began with collecting our materials that we needed. We decided to be as accurate as we could to get first hand information on how well our crops would grow in the same conditions as on our settlement. We spent a total of $200.00 CAD on the following materials: Lunar south pole (LSP-2) high-fidelity moon dust simulant, maple leaf biochar, baby leaf lettuce seeds, and two 2" radius 4" depth indoor plant pots. We filled each pot with nine tenths of the type of soil/regolith and one tenth crushed biochar. The 15 seeds were planted ¼ inch deep. We decided to set up these plants on a counter next to a window that receives high amounts of sunlight on the second floor (artificial light would perform similarly). We measured the time to germinate, plant height, and number of leaves for our quantitative observations. For our qualitative observations, we jotted down what we sensed every day. We watered the plants lightly every day. We decided to fertilize the earth soil once throughout the whole experiment. Below is an image of the original experiment, which began on November 5th, 2024.

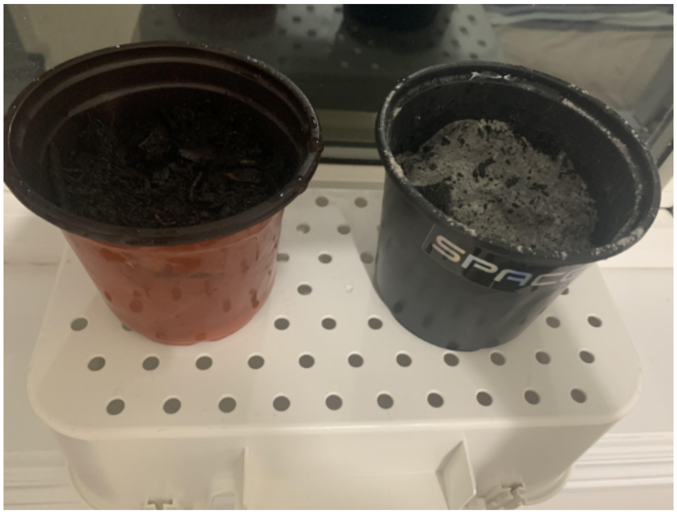
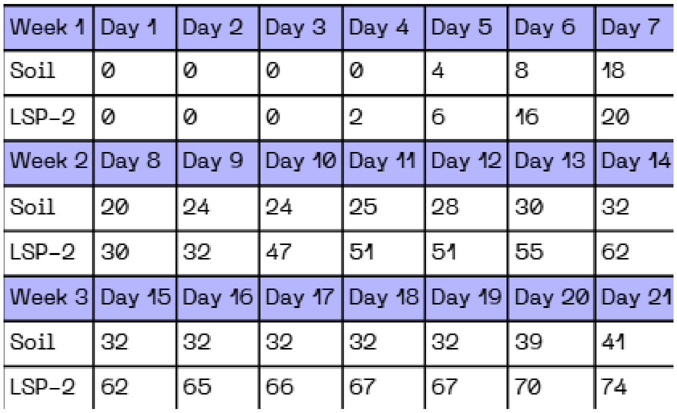


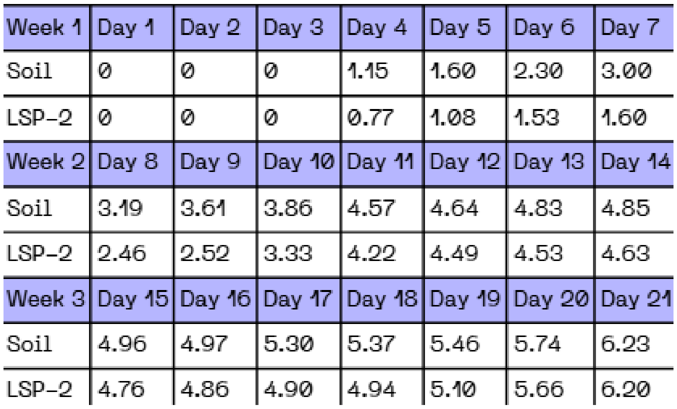
Fig. 19: An image of a the beginning of the experiment before germination. Source: Primary



Week 1	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Soil	0	0	0	0	4	8	18
LSP-2	0	0	0	2	6	16	20
Week 2	**Day 8**	**Day 9**	**Day 10**	**Day 11**	**Day 12**	**Day 13**	**Day 14**
Soil	20	24	24	25	28	30	32
LSP-2	30	32	47	51	51	55	62
Week 3	**Day 15**	**Day 16**	**Day 17**	**Day 18**	**Day 19**	**Day 20**	**Day 21**
Soil	32	32	32	32	32	39	41
LSP-2	62	65	66	67	67	70	74

Fig. 20: Observations for the total number of leaves in each pot over the course of the experiment. Source: Primary

Sight: Crystals formed in LSP-2, plants tilted towards the sun, lunar stems lighter in shade, leaves grew rapidly, plants had germination dicots, third leaf formed at 10 days for both, normal soil leaves spread out, Earth soil plants at same stage of growth (opposite of LSP-2), final plants had four leaves in both pots Touch: Plants felt soft, stems were fuzzy early on, fuzziness vanished over time, plants became moist, third leaf was pointy/spiky, as well as the fourth



Week 1	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Soil	0	0	0	1.15	1.60	2.30	3.00
LSP-2	0	0	0	0.77	1.08	1.53	1.60
Week 2	**Day 8**	**Day 9**	**Day 10**	**Day 11**	**Day 12**	**Day 13**	**Day 14**
Soil	3.19	3.61	3.86	4.57	4.64	4.83	4.85
LSP-2	2.46	2.52	3.33	4.22	4.49	4.53	4.63
Week 3	**Day 15**	**Day 16**	**Day 17**	**Day 18**	**Day 19**	**Day 20**	**Day 21**
Soil	4.96	4.97	5.30	5.37	5.46	5.74	6.23
LSP-2	4.76	4.86	4.90	4.94	5.10	5.66	6.20

Fig. 21: Observations for the average plant heights in each pot over the course of the experiment. Source: Primary

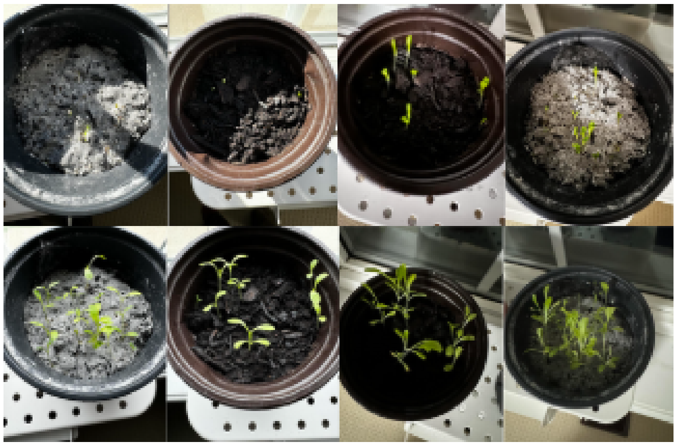


Fig. 22: A visual timeline of the plants' growth over the course of the month. See all photos here Source: Primary

After observing these plants grow over three weeks, a few inferences were made. Most importantly, by the end of the three-week period, both plants were at a very similar stage of growth, being similar sizes and quality. This clearly proves, without doubt, that in the H.E.L.P Modules, agriculture using biochar and lunar soil will thrive and be similar to the ecosystems of Earth.

C. Artificial Atmosphere

To sustain both human and agricultural life on the Gateway R2, we must have an atmosphere that allows for this life to flourish. Here on Earth, our atmosphere is composed mostly of 2 elements with 21% of it being oxygen, 78.5% of it being nitrogen, with the remaining 0.5% being mostly carbon dioxide. This means that we need ways to produce both oxygen and nitrogen on the Gateway R2 ship and lunar bases.

1) Oxygen: The simplest way for our base to produce oxygen is through electrolysis. Electrolysis is when a metal-oxide catalyst is placed in water and a current is passed through the catalyst. This causes the oxygen and hydrogen atoms to split apart, giving us usable oxygen and hydrogen gas which can be pumped out. Water is readily available at the south pole base of our settlement making this process an effective solution. In case of emergencies, oxygen candles will also be stored all throughout both the orbiting and lunar bases. This oxygen will be released in controlled vents allowing us to keep the base at an oxygen level of 21%. Oxygen provided by plants will also provide some redundancy as they can produce a large amount of the oxygen required for the settlement.

2) Nitrogen: To ensure that both life for our crew and agriculture on the settlement is possible, nitrogen is also vital to have in the atmosphere. In an atmosphere consisting of only oxygen, oxygen poisoning is almost guaranteed as our bodies cannot handle such a high concentration of it. For plants, nitrogen is also vital to have in the air to allow for their growth. This is why the methods mentioned below will allow us to achieve an atmospheric nitrogen concentration of 78.5%.

Nitrogen can mainly be generated from the bioreactor also used to produce biochar for crops. Before undergoing thermolysis to produce biochar, organic waste can first be broken down by microorganisms to produce nitrogen. This involves three main steps, ammonificaiton, nitrification, and denitrification. Ammonification is the decomposition of nitrogen in organic matter into ammonia. Next is nitrification, where ammonia is turned into nitrites and then nitrates, which is the usable form of nitrogen for plants. Lastly, there's denitrification where the nitrates are converted to nitrogen gas and pumped into our settlement. Figure 23 shows a diagram of what this nitrogen cycle looks like on Earth. After this process, waste can undergo the thermolysis procedure and be converted into biochar. Additionally, nitrogen tanks will be supplied from Earth during the initial construction and setting up of the Gateway R2, as organic waste isn't a resource that isn't immediately available.

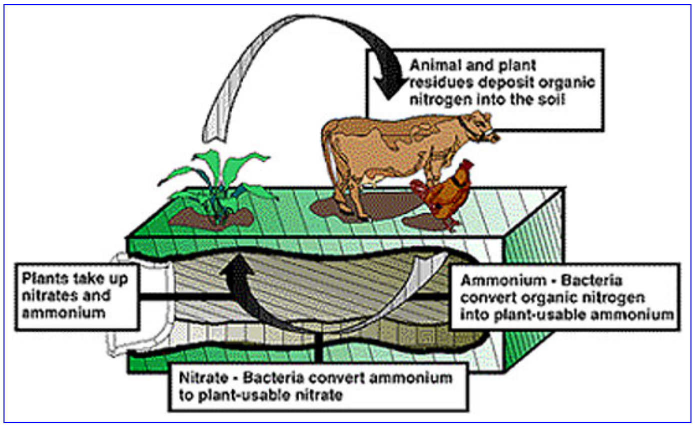

Animal and plant residues deposit organic nitrogen into the soil
Plants take up nitrates and ammonium
Ammonium - Bacteria convert organic nitrogen into plant-usable ammonium
Nitrate - Bacteria convert ammonium to plant-usable nitrate

Fig. 23: Earth's nitrogen cycle. Source: [19]

3) Carbon Dioxide: Excess carbon dioxide buildup in the settlement can primarily be dealt with through all the plants located in the H.E.L.P. modules. These essentially replicate what happens to the carbon dioxide here on Earth. They take in the harmful CO2 and through photosynthesis give back oxygen for us to breathe. However, in places other than the H.E.L.P. modules where excess carbon dioxide absorption may be needed, molecular sieves can also be used. These use crystals of silicon and aluminum dioxide to trap carbon dioxide from the air. When heated this carbon dioxide can be released, making it a reusable filtration method. These two methods will allow for the settlement to maintain an internal CO2 level of 0.5%, enough to allow for agricultural and human life.

D. Waste Management

1) Thermolysis: We had a few requirements for our waste management before we designed it. We need it to use fewer consumables (like oxygen, power, and water), be able to handle all forms of matter (solid, liquid, and gaseous waste), be compressed and not take up too much space, be quiet and not “annoying” for the population, safe, and converted into resources. The solution that we came up with is a process called thermolysis. This process involves a high-temperature reactor that decomposes waste using thermal decomposition to create outputs like oxygen and biochar. These two materials are helpful, especially biochar, which will be expanded on in the method of growing. The consumable usage is limited, as the reactor only uses power, not oxygen or water. The reactor heats up using electrical heating. The temperature inside the reactor reaches up to 650 °C, but the waste is heated, not burnt. Without oxygen in the reactor, the gasses and carbons group with the oxygen in the material, and the waste decomposes. This process is especially effective on organic waste, which is also conveniently the most common type in the settlement. This process has minimum emissions (2g/h of CO_2) as the controlled waste becomes energy. A diagram of the thermolysis process is below.

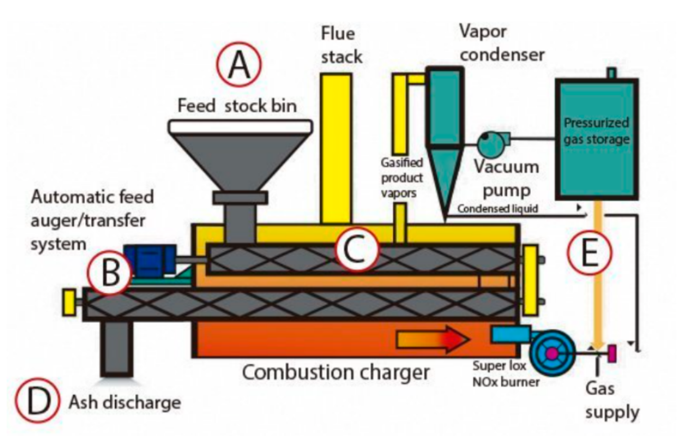


Fig. 24: A specific diagram of a thermolysis reactor + feeding system for treating waste. Source: [20]

2) Feeding System: The feeding system for the thermolysis reactor might seem insignificant, but it is highly inconvenient to design. It is difficult for all forms of matter to enter the reactor, so there are two primary feeding systems. They are a hopper for solid waste and controlled air streams for liquid and gaseous waste. Before entering this system, the trash gets compressed. In the thermolysis process, the trash needs to become small pellets for high efficiency. Air jets are the solution to this issue. Pellets also need to be dried by the feeding system. Those are various requirements for the feeding system. Although, the hopper is quite simple. It is a simple cone-shaped component that consistently feeds solid waste into the compressor. It has a radius of 50 cm and a height of 1m. The radius of the opening is 10 cm to fit the solid waste created on the gateway. The more complicated system is the controlled air stream. We used simple axial fans to directly intake air from our artificial atmosphere system (from the life support modules). The air will carry the liquid and gaseous waste directly into the compressor in ducts. The compressor is the second step in the feeding process, and it compresses all of the waste into small pellets (about 1.5cm radius). 100g of waste enters a small chamber (10cm radius) at a time. The walls are covered in small centrifugal fans (for more pressure) that compress the waste into one pellet (including solid, liquid, and gaseous waste). The pellets move through a slightly warm tunnel through conveyor belts, where they are dried. Finally, the pellets enter the high-temperature reactor and decompose.

E. Electricity

Since many parts of the settlement will be automated, they will need a lot of electricity. Gateway's current PPE generates 60 kW, and we will need much more for this spacecraft, mainly due to the drastic population increase. Our two main sources of this resource are below.

1) Solar Energy: The current Lunar Gateway plan already includes two large solar panels attached to the power and propulsion element. We plan on improving this power source, as we need much more power than the current Gateway plan. The new PPE R2 will include two extra solar panels perpendicular to the original ones. Each solar panel will become 194.95m by 36.58m and generate 480kW of energy total. About (insert number here)kW of power will be allocated to H.E.L.P module A, and about (insert number here)kW of power towards H.E.L.P module B. The diagram below shows the scale differences between the older and newer solar panels.

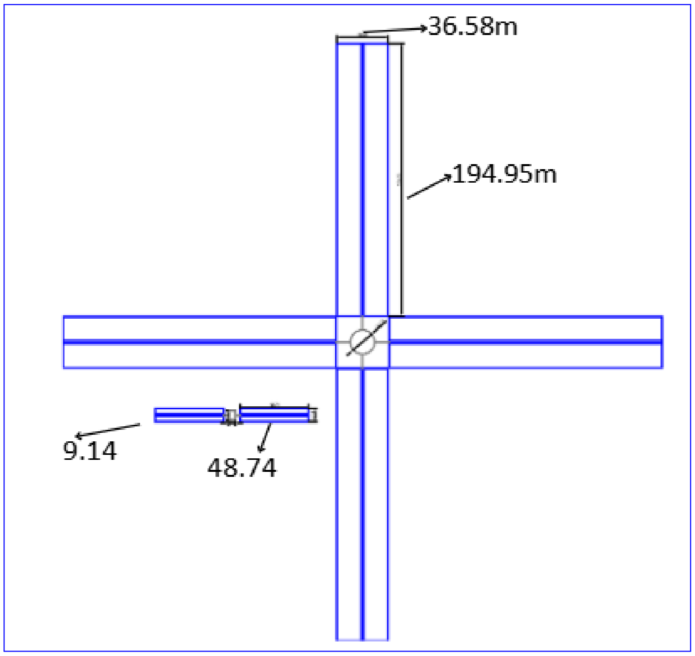


Fig. 25: A diagram visualizing the size differences between the PPE and PPE R2. Source: Primary

2) Nuclear Fusion: The PPE R2 will increase in size to include an extra energy source. This space has nuclear fusion. An element that is abundant on the moon is Helium-3. This material is commonly known to be an isotope that creates safer reactions in a fusion reactor since the isotope is not radioactive and doesn't produce toxic waste. Fusion power is an extreme challenge that can only be efficient with the right technology. The PPE R2 will contain a magnetic confinement tokamak, which fuses helium-3 with deuterium (usually in lunar ice). This reaction will create zero waste compared to the radioactive and toxic waste from fusing deuterium with tritium. The chemical equation for this reaction is

$$D + 3He \longrightarrow 4He(3.6MeV) + p(14.7MeV) \tag{14}$$

Superconducting electromagnets will create magnetic fields that form a circular path inside the tokamak (which is donut-shaped) that the particles will follow to prevent the heated deuterium and helium-3 ions and electrons from colliding with the tokamak wall and losing temperature. The current flowing through the tokamak will provide the heat to bring the plasma to fusion temperature. Inertial confinement was also considered but is much less realistic as an ion beam that could heat the material enough would be highly costly and prone to fail. This new tokamak is a separate layer to the PPE R2. Its operation and maintenance are automatic with aid from Canadarm 3. This tokamak is estimated to provide a supporting power source that generates about 500kW (from every 250kW inputted into the current, Q >2) and will power the ion propulsion system and most other components of the spacecraft. Q is the ratio of power inputted (to heat the plasma) to output power. The energy needed to heat the plasma comes from solar panels. Specifications for the tokamak are: the major radius is 4.024m, the minor radius is 1.506m, and the plasma volume is 180.15 m3. Nuclear fusion on Gateway R2 will not allocate power to the H.E.L.P modules. Below is a labeled 3D model of the nuclear fusion facility (tokamak facility).

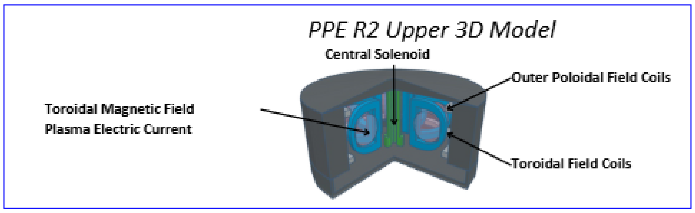


Fig. 26: The inside of the PPE R2 upper stage as a 3D model with the tokamak as the focus, made on Tinkercad. Source: Primary

F. Temperature Control

Keeping a regulated temperature on the Gateway R2 is a crucial task as external temperatures can vary by hundreds of degrees depending on if the settlement is facing the sun or not. An ideal temperature would be one where the crew can work comfortably in t-shirts or casual attire. For this reason, we aim to maintain an internal temperature of between 22°C and 24°C. To maintain this temperature, there are four main systems we require:

1) Heat Production/Collection: The main source of heat for the cabin of the Lunar Gate R2 can come from our electrical and scientific equipment. With most of these devices being electrically powered, they create significant amounts of excess heat which can be used for heating the cabin instead. To collect this heat, a sub-system of heat pipes will be used. These pipes are made of thermally conductive exteriors like copper and a thermally conductive fluid inside (typically water). Figure 27 shows a diagram of how these heat pipes work. These initial heat pipes, which will be referred to as collection pipes, will line around all the major electrical equipment of the settlement and draw away heat. In areas like the H.E.LP. modules where extra heat may be necessary, backup forced air heaters will also be used. These provide the benefit of being portable while also having the ability to warm a whole room.

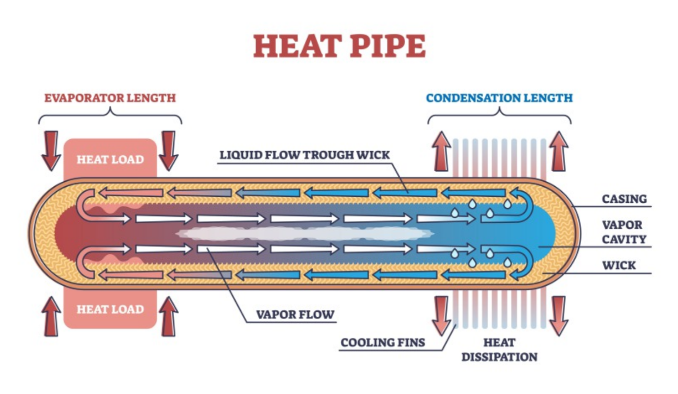


Fig. 27: Diagram of the function of a heat pipe. Source: [21]

2) Heat Transportation: When the collection pipes have taken the heat from our electrical equipment, they will branch off into transport pipes and go all around the settlement to deliver this heat. This includes places like the H.E.L.P modules, habitation modules, and wherever the crew is designed to be. Transport pipes can then be fed into traditional wall radiators. These simply take the hot water in the transport pipes and pump out hot air for the room. With the now cooled pipes, they will connect back to the initial collection pipes, forming a full loop.

3) Heat Rejection: In the case there is excess heat inside the settlement it can be removed in a system similar to heat collection/transportation. The internal transport pipes will be connected to another set of heat pipes called cooling pipes through heat exchangers. Heat exchangers allow for heat to be transferred from one fluid to another without mixing, similar to how a heat sink works in a PC. These cooling pipes will be located on the exterior of the settlement and will also have radiators to keep them cool. When there is excess heat being produced, the heat exchangers can be turned on and heat will be transferred to the cooling pipes, where it will be pumped out through radiators. In areas like the H.E.L.P modules where temperatures may need to be lower than normal, the number of heat exchangers will follow accordingly to allow for more heat to be drawn out.

4) Insulation: This entire system works based on the assumption that there is no external source of heat or lack thereof that can affect the temperature. This means the Gateway R2 must be highly insulated against outside temperatures for it to be habitable. The table below shows possible insulator options for the exterior of our settlement: From the options in the table above, the best insulation material for our purposes would be a combination of Aerogel and MLI insulation. This provides us with an extremely lightweight solution that can insulate radiation, convection, and conduction heat very effectively. The addition of MLI insulation also provides the Aerogel with structural support, making it a more viable option as well.

TABLE XIII: Comparing Insulators

Insulator	**Description**	**Advantages**	**Disadvantages**
Aerogel	A silica based gel in which the liquid component is replaced with air.	Very lightweight, excellent conduction and convection heat insulation, can resist extreme temperatures	Quite fragile and brittle often needing reinforcement, not great against radiative heat
Multi Layer Insulation (MLI)	Consists of multiple thin layers of reflective materials like mylar and insuliting materials.	Very lightweight, effective at insulating from radiative heat	Not as effective against conductive heat transfer
Polyimide Foams	Polyimide foam is a lightweight and flexible foam that is thermally and electrically insulative.	Flexible, can resist extreme temperatures, insulates sound as well	Not as effective against extreme cold temperatures
Vacuum Insulation Panels	These are panels with a vacuum center surrounded by insulative material.	Extremely lightweight, very effective against condutive and convective heat transfer	Very sensitive to pressure changes and won't work if vacuum is compromised

These four systems work collectively to regulate the temperature inside the Gateway R2. Additionally, in the H.E.L.P. modules where temperatures need to be precisely controlled to facilitate the growing of our crops, exact temperature control will be used. The crew can set the temperature of different growing stations simply by adjusting how many heat exchangers or wall radiators are on, allowing for variable temperature control.

V. LUNAR ACTIVITIES

Fig. 28: Source: [22]

As mentioned many times previously, the Gateway R2 will have a connection with multiple lunar bases. Each base has a different purpose and location in the moon-settlement relationship. The main goals are to bring resources, provide jobs, and create more free space for the astronauts in the Lunar system. Each base is introduced and described below, and after that the specific subsystems based around the Moon are explained.

1) Base Persistence: Base Persistence is the first base located on one of the poles of the Moon, specifically the south pole. The South Pole is an area of the Moon covered with craters, one being the 13-mile-wide Shackleton crater which is near where the base will be located. Parts of the lunar south pole like interiors of craters never receive sunlight and are known as PSRs (permanently shadowed regions). Other parts of the pole such as peaks are illuminated by the sun, providing a better place for Base Persistence to be set up.

What makes this part of the moon extremely important is that it is one of the regions where water can be found. Water, in the form of solid ice, is found at the Lunar South Pole as discovered by the Chandrayaan-1 probe in 2009. This ice can be found both on the surface of the Moon in PSRs and underground; roughly 10-15 miles beneath the surface. In total, across both ice deposits, there are about 300 billion kilograms of ice at the lunar south pole that can be extracted and used. Along with this, the south pole of the Moon has ideal lunar regolith (lunar soil) for growing crops on our settlement. For this reason, it will also be extracted and used as one of the methods for growing food (more on that in the Food section).

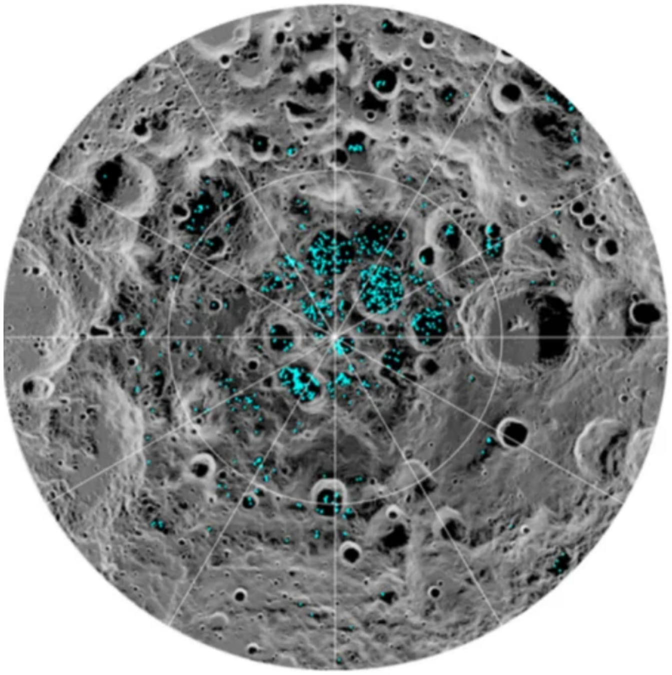


Fig. 29: Water ice on the Moon's South Pole shown in highlights of blue. Source: [23]

The primary goal of Base Persistence will be to extract this ice water and supply it to the settlement and other lunar bases. Most of this work will be automated using programmed machinery, much like the modern production line. Actual crew members will only be there for supervision to reduce the number of people outside the main settlement. More of the actual extraction process will be covered in the resource collection section. The Base will be made of the same aluminum alloy used to construct the revolving settlement. It will also have a system in place to transport the ice collected which will be discussed in further detail in the Water Shipment section. Although mostly intended for machinery and equipment, inside the Base basic entertainment such as books and card games will be included along with a lounge for the rare times there are people there. All in all, this base should be around 1000 square meters based on estimates of the average size of a factory to fit all the components described.

2) Base Excellence: Base excellence is the second base located on one of the lunar poles, specifically the north pole near the Plato crater. The north pole of the Moon is similar to the south as it consists of standard light grey lunar regolith with many craters scattered throughout. Because of this the lunar north pole also has many PSRs, which is why it will be set up on a peak like Base Persistence. More importantly, the North Pole, just like the South, features ice water both underground and on the surface. Although it may seem like the more inconvenient option, there is more underground ice than the surface, making it the main source of water. The amount of water both surface and underground is around 300 billion kilograms, making the total amount of water on both poles around 600 billion kilograms.

Like Base Persistence, Base Excellence will also focus mainly on gathering this water from the lunar north pole. The overall setup of the base will be very similar to Base Persistence with mostly automation, shipment systems, and some leisure activities. The main difference between the two bases is in terms of size, as Base Persistence has to focus on collecting both ice and lunar regolith, while Base Excellence only focuses on collecting ice. This is why the size of the base will be around 700 square meters, similar to Base Perseverance.

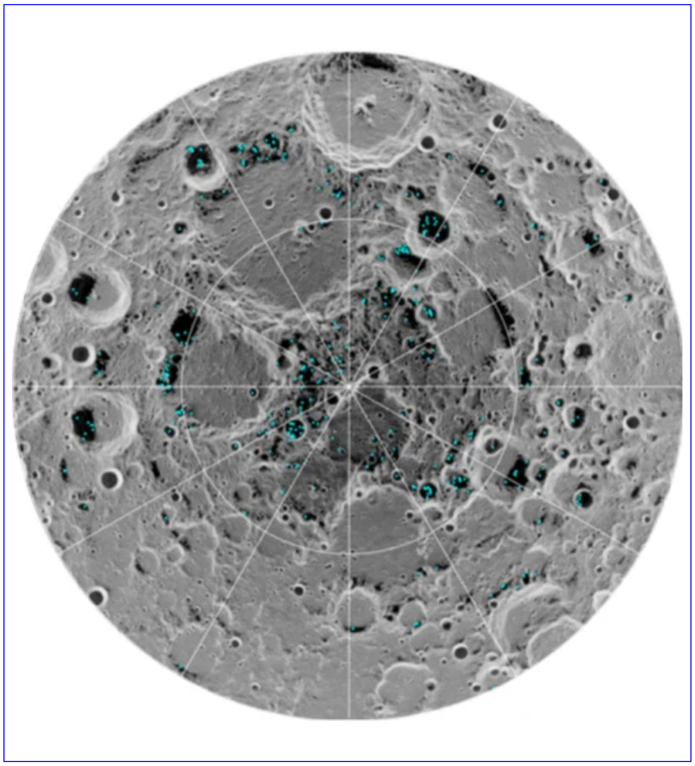


Fig. 30: Water ice on the Moon's North Pole shown in highlights of blue. Source: [23]

3) Base Perseverance: Base Perseverance is the first equatorial base, specifically located near the Keplar crater (the western part of the Earth-facing side). This side of the Moon distinctly features the dark part which takes up a significant portion of the Moon we see in the night's sky. This visually dark part looks that way because it is made up of a substance called lunar Mare (plural Maria), which is ancient dried-up lava flows. This not only has an interesting visual appearance, but it is also a crucial resource as lunar maria is rich in Helium-3. Helium-3 is a vital element for the Gateway R2 as it is the fuel source for our fusion reactor, which is one of the main energy sources for the settlement.

As a result of this vital resource, Base Perseverance's main priority will be on extracting the Mare from the Moon's western equatorial region. The specific extraction techniques will be explained further in the Resource Collection section. The base will include a shipment system similar to that of the shipment system used to deliver water (more on that in the Water Shipment section). Processing of the lunar Mare will also take place so that the Helium-3 is usable by the reactor. This simply involves heating the mare to about 700°C, which causes the Helium gas to separate. Apart from that, Base Perseverance will be mostly autonomous with little crew members inside. Simple things like access to pre-made food, water, and basic entertainment will be available, however nothing for long-term survival. To support all these operations, the size of the base will be roughly 700 meters squared, taken from estimates of the size of a small factory.

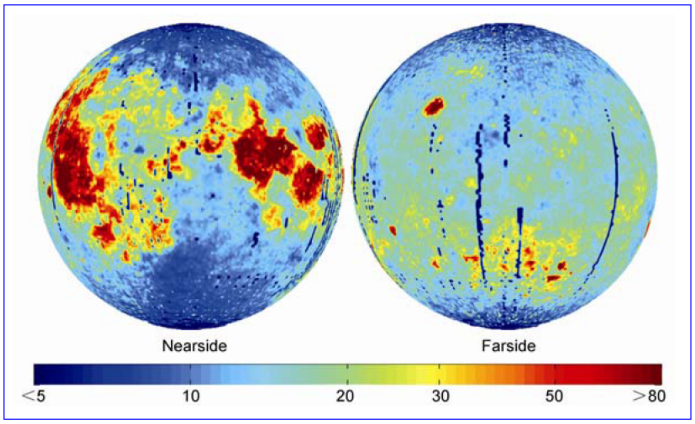


Fig. 31: Map showing concentration of Helium-3 on the Moon. Source: [24]

4) Base Resilience: Base Resilience is our last base and is the second base located on the lunar equator. Specifically, Base Resilience is located near the Langrenus crater (the eastern part of the Earth-facing side). Just like the western side, the eastern part of the Moon is composed of significant amounts of lunar mare. However this Eastern part of the Moon near the Langrenus crater generally has a more regular lunar regolith. Luckily, Helium-3 can also be found in this normal lunar regolith as well, meaning it can also be extracted for use. This lunar regolith and mare are once again highly useful for our settlement as the Helium-3 available in them is used to power our nuclear fusion reactor. The overall setup and design of the base is essentially the exact same as Base Perseverance, as both serve to perform the same functions. The processes involved in extracted lunar mare and regolith are generally the same, as both are automated with few crew members. They also will include the same basic entertainment and a method of communication between the bases and the orbiting settlement (more on that later). However, the only real difference is that Base Resilience will also collect normal lunar regolith, and for this reason its size will be slightly expanded to 800 meters squared. This is based on the estimates for the size of a modern day medium to small sized factory.

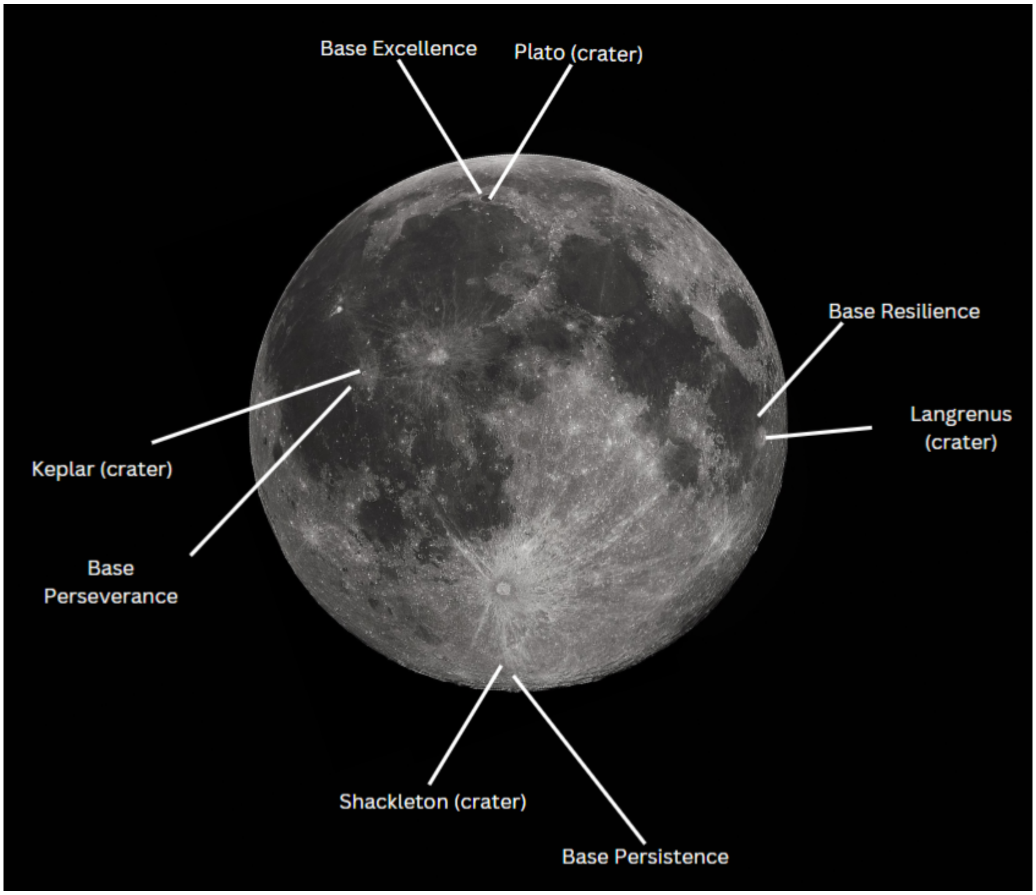


Fig. 32: A map outlining the locations of all Lunar Bases with close landmarks. Source: Primary

A. *Resource Collection*

On the Moon, the most significant activity is to mine and collect resources for the entire settlement's systems. There are many parts that need resources from the Moon to function. Firstly, for the Tokamak Reactor to perform nuclear fusion, Helium-3 must be acquired from the Lunar Regolith. Second is water from the poles for agriculture, drinking water, and deuterium. Finally, Lunar regolith is needed for agriculture.

Helium-3 is the first material being mined. It is found in the regolith/dust on the Moon's surface, as the Moon has been bombarded by solar wind for billions of years. Ionized hydrogen and helium came from this solar wind, and because of this helium-3 is now available in Lunar Regolith. Lunar Regolith has helium-3 in a ratio of 10-20 to a billion. At least a hundred million tons of Lunar Regolith is the minimum to get one ton of helium-3. Once Lunar Regolith is extracted from the bases (mainly perseverance and resilience), it must be processed to separate the helium-3 and prepare it for Nuclear Fusion. One method is to heat the Lunar Regolith and separate the helium-3, which according to figure 33 can be separated from Lunar Regolith at temperatures of 1000 degrees Celsius. Using this information, reactors will be established at all four Lunar Bases to process a fraction of the Lunar Regolith and ship the helium-3 to the settlement. Another method to extract helium-3 could be to use an autonomous mining robot with interior components similar to figure 35. It has its own built-in reactor. However, this method releases extra volatiles, or elements from the Lunar Regolith, causing contamination. The final method is to reduce the displacement of Lunar Regolith, and instead have a large autonomous vehicle carry heat rods, pipes, or domes that can be placed on or in the Lunar Regolith to process large quantities of Lunar Regolith at a time. Our final decision was to incorporate both the first and last methods, with autonomous robots collecting Lunar Regolith to be processed in the bases, along with the large autonomous "cranes" with heated tubes processing large areas.

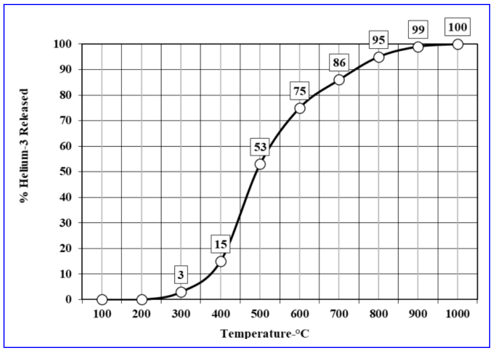


Fig. 33: A graph showing the rates of helium-3 release correlating to temperature. Source: [25]

Water is another material extracted by these bases, and it will be extracted at base excellence and persistence. Water is used for the automated agriculture in H.E.L.P Modules, to drink, and for deuterium. Deuterium is the second element involved in nuclear fusion with helium-3, and it is common in large bodies of water or ice. To get water, there is one efficient method that works at both the North and South poles. For the South Pole, there is a creative proposed method to extract water without much processing. An autonomous vehicle (quite small) is sent to the locations with water, as seen in the last few pages about these two bases, and they will drill into the water to extract it. The drills will be heated, so once the ice is drilled in, it evaporates. The water vapor is collected and condensed in a closed loop into liquid water, allowing for easy storage and transportation. There will be many of these vehicles traveling around major ice hot spots and collecting water around Base Persistence. This method is also the most energy efficient method to extract water.

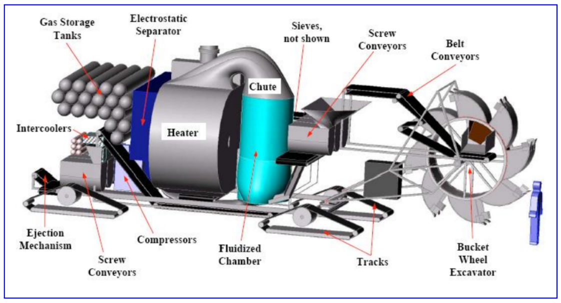

Gas Storage Tanks
Electrostatic Separator
Sieves, not shown
Screw Conveyors
Belt Conveyors
Chute
Intercoolers
Heater
Ejection Mechanism
Screw Conveyors
Compressors
Fluidized Chamber
Tracks
Bucket Wheel Excavator

Fig. 34: Caption = Fig. 35

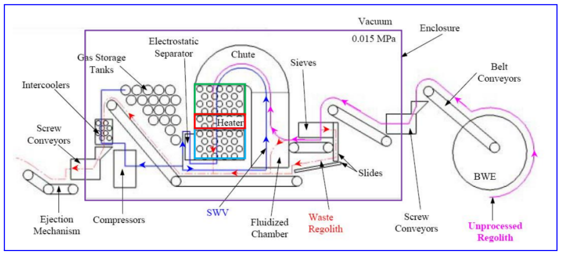

Vacuum
0.015 MPa
Enclosure
Electrostatic Separator
Gas Storage Tanks
Chute
Sieves
Belt Conveyors
Intercoolers
Heater
Screw Conveyors
Slides
BWE
Ejection Mechanism
Compressors
SWV
Fluidized Chamber
Waste Regolith
Screw Conveyors
Unprocessed Regolith

Fig. 35: Diagrams showing the autonomous mining vehicles with a built-in heater. Source: [25]

The final crucial resource that is extracted at the bases is Lunar Regolith in its pure form. As seen previously, Lunar Regolith is excellent as a passive radiation protection method. This is why it will be extracted in mass to cover all bases on the Moon, providing protection from GCRs and SEPs. Lunar Regolith is also used for farming as seen previously. It is used to grow many crops and is one of the most important parts of making the settlement self-sustaining. It will be harvested at mainly the equatorial bases (Perseverance and Resilience). As explained in the section about helium-3, one of the methods of collecting Lunar Regolith is autonomous robots scattering and shoveling large amounts of Lunar Regolith. Half of this will be processed in the reactors at the bases to extract the helium-3, and the other half will be used for agriculture on the settlement. These autonomous robots are designed similarly to snow plows, but designed to survive on the Moon with its dangers.

B. Vehicles

The main purpose of vehicles in our settlement will be to traverse the surface of the moon. Through this, we will be able to transport materials and scout new areas of the lunar surface. Vehicles are also needed for people to travel from the 4 bases. This is because all of them don't have supervisors at all times so we will need to get to and from the bases. This means that we need a vehicle with a capacity of at least 4 people to be able to transport them across the surface of the Moon. These vehicles will also have the ability to run completely autonomously. This is because it reduces the number of people needed to run the vehicles, and saves the crew members effort. However, vehicles can also be manually controlled.

The vehicle we use for our specific purposes is the Moon Racer. This is a vehicle designed by Intuitive Machines (IM). They created a $30 Million contract with NASA regarding the Artemis program. IM has made a fully autonomous and electric Lunar vehicle. This is extremely beneficial for the needs of which we need this vehicle. This vehicle also features a hazard avoidance feature. As we know the surface of the Moon is not flat at all, we need a system to avoid these obstacles and the vehicle by IM has that. We can also use solar panels to generate energy for the vehicle so it is an extremely efficient vehicle energy energy-wise.

Along with all the in-built features of the Moon Racer, we will be including a few additions to make it better suited for our environment. First off, along with solar panels, hydrogen fuel cells will be used as an alternative energy source as areas near the pole receive little to no sunlight. These hydrogen fuel cells can come as a byproduct of the electrolysis reaction used to produce oxygen throughout the settlement. Vehicles will also be equipped with larger, more rugged suspension as the lunar surface is covered with craters and rocks. Lastly, our final version of the Moon Racer will include the addition of a carrier at the back of the vehicle. This is to attach extensions such as carrying beds to transport materials between bases.

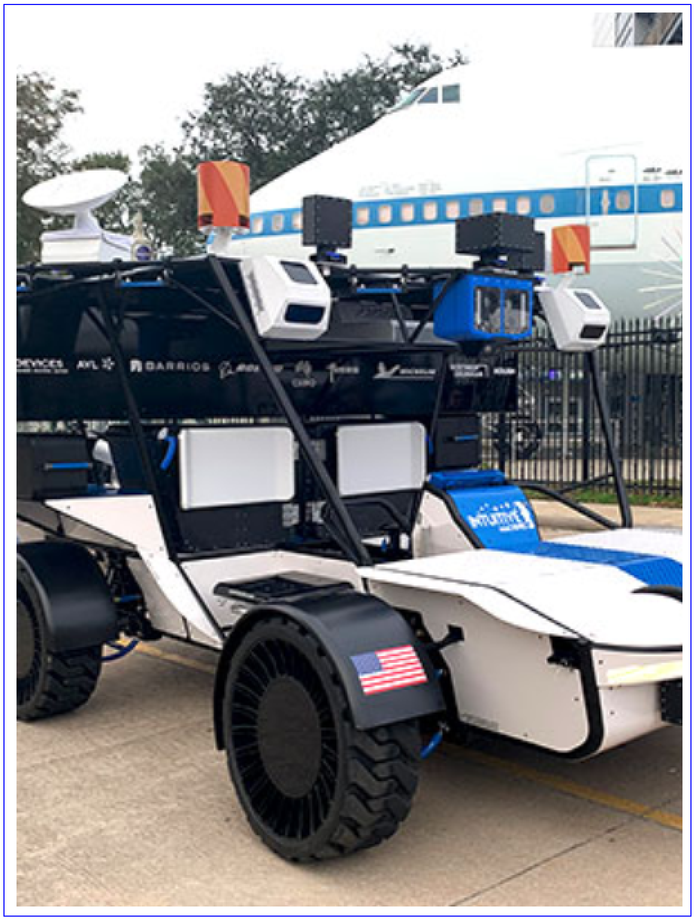


Fig. 36: The Moon Racer; a possible vehicle for traversing the Lunar Surface. Source: [26]

C. Communication

A very important factor in having successful bases and a successful settlement is communication to those back on Earth. This is why there are multiple methods of communication to make sure it is never severed, and all three parties can communicate with each other seamlessly and fast.

First, let's go over how the internet works. The way that the internet works is quite simple, data is transferred from servers to the receiver. That is what the internet is in simple terms, however it's how the data is transferred that is difficult. For example, when you are watching a video, you receive data from the server that is storing the video in giant storage places. This server can be miles away from you, to use a satellite to transfer videos from that magnitude of a distance, it will be difficult and time consuming. Along with that there are also risks of losing information during the time that the data is being transferred. So what is the solution? We will be using a network of fiber optic cables routed from all the bases of our settlement to each other. The cables will start at Base Persistence, and be connected to the 3 other bases. Base Persistence will act as the main base from transferring data from the surface of the moon to our orbiting settlement. Five areas will be equipped with routers, the orbiting settlement, Base Persistence, Base Perseverance, Base Excellence and Base Resilience. The satellites connected to our settlement will be able to send and receive data from the internet of Earth, then they will store the data. This data transfer will happen using antennas attached to Base Persistence and our orbiting settlement. Setting up connection to the Earth's internet is a great way to make the transition from life on Earth to space more manageable for the people of our settlement. This way they can still hold onto things that they cherish doing on the internet. This will also help us in communications as setting up a network of fiber optic cables allows us to transfer data from bases with immense speed.

The fiber optic cables will help us create a network that will efficiently be able to transfer data from each of the bases. This creates a network that is beneficial for our settlement in ensuring that information is transferred to other sections of the settlement in a timely fashion. From there, Base Persistence will be used as the main hub to transfer data to our orbiting settlement. This is how we will communicate in between all the sections of our settlement.

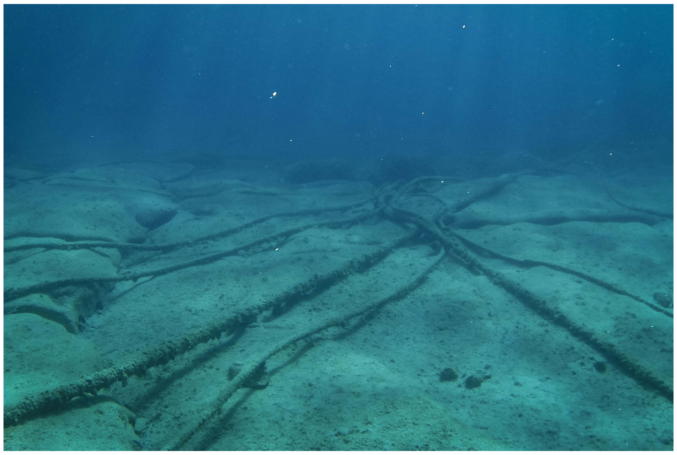


Fig. 37: A fiber optic cable under Earth's oceans, similarly to how fiber optic cables will traverse underneath Lunar Regolith. Source: [27]

VI. SOCIETY

Fig. 38: Source: [28]

1) Leadership:

This section covers the leadership of the settlement. Specifically, it explains how the settlement will be managed, who will be managing it, and the system of government.

2) Education:

The education part explains how students will learn on the settlement, as over time the settlement will grow and there will be younger astronauts who need to learn.

3) Jobs:

Jobs are crucial in any society, which is why this section is here to describe how jobs function on Gateway R2. The specific system is identified, with connections to all modules of the settlement that do not have automation/

4) Mental Health:

Mental health is one of the most important part of managing any society, making sure everyone is healthy mentally. This section covers entertainment and how the mental health of all astronauts will be kept.

A. Leadership

Moving on to the government, our team wanted everyone to be involved in decision-making around the settlement. There were many different and innovative ways to do this, which left us very confused. However, then an idea came up, the idea of Participatory Circles. Participatory government is a type of government where citizens are actively involved in making decisions to shape public initiatives. This type of system emphasizes the involvement of citizens. This type of government gets citizens involved in activities that they would not normally do. This type of government highlights:

1) Citizen Engagement: As citizens are all expected to participate in decision making due to this system of government, this is an important aspect of Participatory Government.

2) Inclusivity and Diversity: As the Participatory government requires everyone to participate, there are a wide variety of people involved in this decision making. This means that since there is diversity of many demographics of people, decision making can be well suited for each type of citizen. This provides a better overall opportunity for growth and development on our settlement.

3) Transparency: As everyone from the settlement is involved, this reduces the risk of any unexpected things happening. Everyone will be involved in the types of decisions made. This ensures that there are no disputes afterwards which helps avoid conflict. This is another thing that will help the overall mental health of people in our settlement.

4) Decentralizing Power: In many government systems that exist today, power is very centralized. For example in dictatorships, the power is focused at the top. While this does have its advantages like quick decision making, there are also many disadvantages. The leader can not take a look at the day to day problems. In this way, centralized power is very bad for the overall community. Now moving on to Participatory government, as all citizens are involved, they all understand the issues that they go through on a daily basis. This means that decision making will be targeted down to specifics and solve the issues that are really causing people problems.

5) Continuous Learning: As this process involves all types of people, people will constantly be giving input to this project. There will always be a strive to get better and learn. When interacting with others around you, your desire to learn grows and strengthens. This type of government will ensure innovation and learning for people of our settlement.

There are 4 sections to this government, Sustainability, Innovation, Community and Operations. 25 people will be placed in each of these sections, they will be rotating every 6 months to another section. During the first term, everyone will join categories based on their experiences and interests. Every 2 weeks all the sections will meet amongst each other to discuss important issues within the section. For example, you could be responsible for organizing events if you are in the Community section or mentoring kids. Every 3rd meeting (Every 6 weeks) all the sections will get together to discuss issues amongst the other sections. Any information will be uploaded to a server for everyone to access to ensure that everyone has access to crucial information.

Overall, this style of governance helps give power to each of the people involved. There is no time where the people can feel that they were not given the right to choice, they will always hold some control of the decisions that happen in the settlement. This ensures that social cohesion and our desire to have social interaction is met. By having control over important decisions that will inevitably change their lives, the residents will feel as if they are in somewhat control. This helps with ensuring that their mental wellness is kept in mind. This system works perfectly for our settlement as it helps us fulfill key goals that we have regarding what a government should strive to achieve.

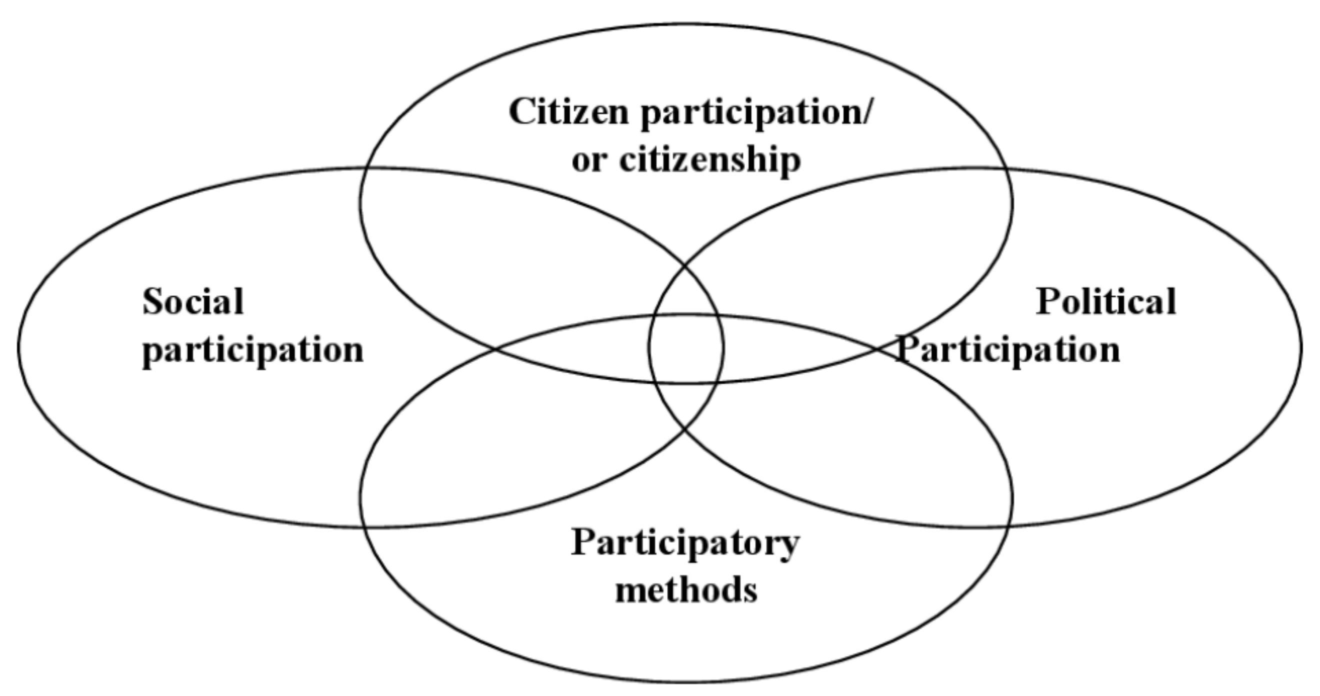

Citizen participation/
or citizenship
Social
participation
Political
Participation
Participatory
methods

Fig. 39: Source: [29]

B. Education

Having a proper education is highly important to ensure our youth will be able to sustain our settlement and grow it for further generations. To do this, the schooling system will split into 3 main sections to gradually progress students through their studies.

1) Students aged 4 to 12 (grades 1 to 8) will go to primary school to build their foundational skills. They will mostly focus on basics like reading, writing, algebra, and typical subjects taught in school. This stage of schooling is required in order to build a foundational understanding for the tasks and topics covered in the next stage of schooling.
2) Students between the ages of 13 to 17 (grades 9 to 12) will attend secondary school. The purpose of secondary schooling is to delve further into common subjects and give an opportunity for the students to decide what their career path actually will be. This means that secondary schooling will involve both theoretical lessons and hands-on learning, so that students can get an idea of what they want to do in their last step of schooling.
3) The last step of schooling is for students between the ages of 18 to 20 and is called Practical. This higher education will be required for everyone as it is where students get to focus on one field of study, including things like Science, Mathematics, Computer Science, Biology, Agriculture, and Law. This step of schooling will almost entirely focus on hands-on learning and on-site training so that the youth can get working experience as early as possible. This hands-on training will directly translate to the work being done by professionals in their respective fields.

Fig. 40: An example of hands-on learning on Earth, with physical objects. Source: [30]

For each stage of education, schooling will begin in September and end in June. The school day will last from 9:00 p.m. to 3:00 p.m., with a break in the middle of the day. Schools will also highly promote extracurricular activities with opportunities for things like sports, clubs, and instruments. Students will be graded on a 100-point scale and those who score highly can skip a grade depending on the circumstances. The focus on hands-on learning in later years is because on the settlement it is generally more important for us to youth who can complete hands-on activities rather than just knowing the theory behind the settlement.

C. Jobs

Jobs on the Lunar Gateway R2 will be in many fields, including Science, Mathematics, Computer Science, Biology, Agriculture, and Law. For youth, their field of work will be decided by what they choose to specialize in their last step of schooling, while for those just arriving in the settlement, jobs can be determined by experience and skills. No matter which field members of the settlement choose to work in, they'll have two options, either teaching or working for the settlement.

1) If a member of the settlement decides to use their background knowledge and specialization to teach further generations, they will be placed in one of the three schooling levels. This can be based on the level of their background knowledge and experience and also how they performed in school. By choosing a career in teaching, a cycle is created where new batches of students can be taught continuously. The specializations of these teachers are also beneficial as they can provide a great depth of knowledge for certain subjects.
2) If a member of the settlement instead decides to use their education to instead work on the settlement, they will be placed in a job position that suits their experience. Most if not all jobs on the settlement will involve hands-on work that directly affects the settlement like repairs and growing plants. Having jobs that are mostly hands-on is vital as it gives the crew a better sense of how to sustain and maintain the Gateway R2. These jobs will also look towards the development of certain aspects of the settlement, including expanding modules and redesigning equipment. Examples of these practical style jobs include mining technicians, electricitions, agricultural engineers, welders, and more.

Fig. 41: A welder is a common skilled trade that will be prevalent on the settlement, with many of this kind of worker. Source: [31]

Working age citizens on the settlement (20 and above) will have to work at least one of these jobs unless in the case of mental or physical disabilities. Both educators and practical workers will be able to retire at the age of 60. After that, instead of pensions and government support, senior citizens simply will be able to live for free without the need of going to work (unless they choose to). The job schedule will be from Mondays to Fridays from 9am to 5pm (both based on Earth timings). This schedule may be affected for those working as extraction and mining technicians at the lunar bases due the transportation time between the lunar bases and revolving settlement. The work structure on the Lunar Gateway R2 is one that mimics the Earth's, however with a greater focus on practical work.

D. *Entertainment*

As previously mentioned, a main focus of the group is to prioritize social interaction. For this there are systems set up in place to encourage community gatherings and festivals. A group of people are assigned to host festivals to engage with the community.

Moving forward, another way to engage the community is by films. Every week there will be movie nights for everyone to get together and interact with one another. A giant projector screen is set up for the people with 100 seats. Our state of the art theater with 3D films. The projector screen will be polarized and everyone will be given specialized 3D glasses to enjoy films in 3D, in outer space.

For many of us in the 21st Century, the internet has become an addiction. We believe that life without the internet would be miserable. For this reason, transitioning to a society without the internet would be an issue that many would not be able to adjust to. In all of our lives, the internet is very heavily involved. It is quite uncommon for the average person to be able to go a day without any sort of use of the internet. We knew that this would be a big issue so we decided to implement the internet into our settlement.

Finally for entertainment, we have decided to develop a new sport: Lunar Jumpball. This sport will be played on the surface of the moon around all the bases. A circle of 30m diameter is the arena of this sport. There will be 3 hoops set up on opposite sides of the arena, these hoops are 2m in diameter. Each hoop will be set up in 5m increments, starting with 5m, going to 10m, and finally the last and tallest hoop will be 15m high. The playing ball for this sport will be 25cm in diameter. This ball will be made of silicon with grips to ensure the ball does not go flying in outer space. The ball will be made with aerogel inside the silicone casing as this will help to lower inertia.

Fig. 42: Source: [32]

1) *Lunar Jumpball Rules:* Teams:

- Teams consist of 4 people on each side
- Teams must have assigned roles (1 attacker, 2 defenders and one midfielder)
- After each point scored, teams are required to rotate positions to ensure that everyone gets a chance to play each role.

Traversing the Field:

- Players are allowed to jump once if they are holding the ball
- Players can jump around the field, but they must come down within 7 seconds if they are holding the playing ball
- The ball must be passed every 10 seconds otherwise it will be a possession foul and the ball will be granted to the other team

Scoring

- Scoring will be done in a manner similar to basketball, every time you score the ball into one of the 3 hoops you will be granted points
- The number of points you score depend on the hoop you score the ball in
- The shortest hoop (5m) grants 1 point, the 10m hoop grants 2 points and lastly, the tallest hoop (15m) grants your team 3 points.

Bounds

- If you step outside of the 30 diameter cicle, it results in an immediate turnover and loss of 1 point

Physical Fouls

- If you physically foul another player, you will be suspended from the game for 2 possessions, on top of that your team also receives a deduction of points

This game brings basketball to the stars, it is an innovative take on the sport to adjust the conditions of outer space. Overall the inclusion of this sport is sure to be entertaining for residents. Even if there are not a lot of people that can participate in the sport at once, it is a sport that is competitive. Using the moon's gravity to jump really high to reach the hoops is an innovative idea to help adjust to conditions on the surface of the Moon. This sport will also strive to bring unity to the people as people can gather to support their favourite team and competitions and events can be set up surrounding their sport. As the 4 bases will each have their own, unique playing field, each game will be different from the last, played in different physical locations. A sport like this is not only entertaining for people playing but also watching, this also acts as an outlet to relieve stress and improve overall mental health.

E. Mental Health

Society is a critical aspect of our settlement. Our goal is to create a healthy society with lots of social cohesion. According to studies, having social interaction with others has 4 key benefits. Firstly, it boosts your overall mood and reduces stress. Being in unfamiliar surroundings being in space can be taxing on the human mind. Social interaction ensures the transition is more peaceful and doesn't cause too much stress on the residents. Social interaction also improves quality of life and mental well being, reduces the risk for chronic disease, and slows cognitive decline. Now that the benefits of social interaction have been clarified, let's move to how this will be achieved. The settlement aims to achieve the goal by having community places where citizens may gather and meet up to increase their social interaction. Another way the settlement aims to achieve the goal is by having festivals for important events (i.e 6 month, 1 year anniversaries, etc...) This increases the social interaction between people which works towards the goal of the settlement to increase social cohesion. As the settlement size is small, everyone is required to attend debates regarding issues on our settlement, this way people get out and actually interact with one another and share their thoughts and ideologies.

Moving to another very important topic, we have mental health. Mental health is a state of well-being in which people can deal with the day-to-day struggles of life. Just because you can not see it doesn't mean that it isn't as important as other types of health like physical health. Mental health means more than just being free of any types of mental illness. Mental health is something with more depth and complexity. Although it is true that people with mental health illnesses often suffer from worse mental health. There are many things that influence our mental health throughout our life. Individual problems such as substance use and genetics play an impactful role in the mental well-being of individuals. There are a whole other variety of factors that influence mental well-being. These can include your geolocation, childhood conditions (i.e parenting) and many more. In our settlement it is very important to us that we prioritize the mental well-being of all others around us. There are several key things to having good mental health, these consist of:

- Believing and feeling that you are in control of your life and personal decisions
- Being able to deal with the stress of the hustle and bustle of everyday life
- Being optimistic about events that have happened or are going to happen in your life
- Feeling physically fit and healthy

Ways that we are going to achieve these goals:

- Good working conditions
- Healthy eating and sleeping pattern
- Physical activity
- Reward work and school experiences
- Access to resources such as councelling

By putting these practices into play we as a team can ensure that we provide support to anyone's mental health that might need some help to get in a healthy state, this is a big priority as members of the group have been through some mental well-being problems, so we understand the value of mental well-being.

VII. IS IT REALISTIC?

Fig. 43: Source: [34]

The realism of the settlement is one of the most important parts of planning any venture into space. In this section, the cost will be accurately calculated using all of the information on this report to find an estimated cost.

A. *Costs*

Breakdown:

1) Research and Development (R&D)
    - Tokamak Reactor: $30-50 billion due to new technology and testing
    - Gravity Generation: $10-20 billion due to first implementation and structural stability and research
    - Radiation Shielding: $5-10 billion due to new active radiation shielding, as well as testing
    - Canadarm 4s: $5-10 billion due to logistics of having many more than just one
    - Skyhooks: $30-52.5 billion due to logistics, planning, timing, and testing
    - Mining Systems: $30-52.5 billion due to robotics and autonomous concerns, along with new technology for the Moon's terrain and resources
2) Manufacturing
    - HALO R2: $35-55 billion because it is a large module with gravity
    - Lunar I-Hab R2: $45-65 billion because it is also a large module with gravity, similar to HALO R2
    - H.E.L.P Module A: $15-20 billion because it is a slightly smaller module with gravity and many complex agriculture systems (aeroponics, hydroponics)
    - H.E.L.P Module B: $25-40 billion because it is similar to H.E.L.P Module B but larger with a waste management system.
    - Solar Panels: $20-30 billion due to extremely large size
    - Tokamak Reactor: $50-70 billion due to advanced technology and large reactor size, also automation.
    - Orion R2: $15-20 billion although original Orion was 20 billion, technology has advanced far since then, reducing the price even though the module is larger with a lander
    - Debris Shielding + Radiation Protection: $30-50 billion for all the materials and shields, majority comes from active radiation protection
3) Launch Costs
    - Number of Launches (during initializing of the settlement, with all assembly, people, supplies, and more: about 50-70
    - Cost for Each Launch: $2-3 billion due to large transport vehicles such as the SLS
    - Total Cost of Launches: $100-210 billion
4) Assembly
    - Construction in Orbit: $40-60 billion for salaries and support
5) First 10 Years of Operation
    - Crew Salaries (100 astronauts): $100-150 billion, as $10-15 billion a year with $100,000-150,000 salaries
    - Supply Missions: $50-100 billion with $5-10 billion a year for water shipment missions in the first 10 years before Lunar Bases begin shipping larger amounts of water
    - Maintenance and Energy: $50-100 billion from $5-10 billion a year

Category	Low Estimate	High Estimate
R&D	$60B	$105B
Manufacturing	$235B	$350B
Launches	$100B	$210B
Assembly	$40B	$60B
Operations	$200B	$350B
Total	$635B	$1.075T

TABLE XIV: Total Estimated Cost

After comparing these prices to the cost of the ISS, it is clear that these prices are a realistic estimate. The ISS costed about $150B to manufacture, while this costs $235-350B. This makes sense due to the larger size and new technologies. The logistics and launches with new technology also increase those two values as well as R&D by a lot of money compared to the ISS. Operations are increased drastically due to the self sustaining nature of Gateway R2, as well as the Lunar bases. After examining all of these factors, the total price of creating Gateway R2 is $635B - $1.075T.

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